# EXTRACTION OF THICK COAL SEAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**

**In**

**Mining Engineering**

By

**SNEHENDRA KUMAR SINGH**

**107MN023**

DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA-769008

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Under the guidance of

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# *CERTIFICATE*

This is to certify that the thesis entitled, "**Extraction of Thick Coal Seams**" submitted by **Mr Snehendra Kumar Singh, Roll No. 107MN023** in partial fulfilment of the requirement for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

Date:

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## ACKNOWLEDGEMENT

First and foremost, I express my sincere gratitude and indebtedness to **Dr. S. Jayanthu**, Professor of Department of Mining Engineering for allowing me to carry on the present topic "**Extraction of Thick Coal Seams**" and later on for his inspiring guidance, constructive criticism and valuable suggestions throughout this project work. I am very much thankful to him for his able guidance and pain taking effort in improving my understanding of this project.

An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

At the last, my sincere thanks to all my friends who have patiently extended all sorts of helps for accomplishing this assignment.

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# ABSTRACT

This project presents numerical model studies on stress analysis during depillaring of 5-11m thick coal seams at depth range of 150-900m at an interval of 150m. Finite Difference Code – FLAC (fast Legrangian analysis for continua) was used for understanding the influence of depth and thickness of coal seams on stress distribution over pillars, stooks and ribs at development stage and depillaring stage through parametric studies. 24 numerical models with different configuration representing the parameters in field experimental trials are used. Variables of the parametric studies for stress analysis are: seam thickness in the range of 5 – 11 m at an interval of 2 m and depth cover of 150 m to 900 m at an interval of 150 m.The maximum on pillar was found to be 35 MPa at 900m depth in 5m thick seam and the minimum was 5 MPa at 150 m depth. The maximum stress on stooks and ribs was found to be 70 MPa and 10 MPa in 5 m, 7 m at 900 m and 450 m depth respectively.

From model it was found that thickness of the seam does not have any effect on the stress behaviour of the pillars after development work. Parametric studies through the numerical models indicated decreased vertical stress over the stooks with increasing height of the extraction at the depth covers in the range of 150-900 m. Though the stress coming was less, the stooks were getting yielded very soon due to increase in height of the stook and increase in height to width ratio.

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# *INTRODUCTION*

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# *OBJECTIVE*

# 1. INTRODUCTION

Around 70% of the total coal reserves of India are excavated by underground mining methods only. But underground extraction of coal could not achieve much importance due to the difficult geo-mining conditions of the coal deposits and unavailability of adequate engineering support to meet the required level of safety and rate of production. Although underground extraction of coal is considered as a part of CCT (clean coal technology), the share of coal production in the country by opencast mining has been continuously increasing during the last 50 years(R Singh – 2001).Fast mechanisation of mines, short set-up gestation period, and high production and productivity are the main reasons behind the growth of coal production by opencast mining. As the coal reserves suitable for extraction by opencast mining are becoming fewer in number, mining methods for safe and effective underground winning of coal are going to play an important role in future coal production.

In India, coal seams of 4.8m thickness or higher are called thick. Nearly 60% of the total coal reserves that are workable by underground mining methods in the country are thick coal seams. To fulfil the increasing demand of coal, most of these thick coal seams have been developed extensively in single or multiple slices/sections. Around 30% of the developed thick seams are underneath a protected surface, while the remaining70% are available for caving subject to the availability of a suitable mining method to extract coal under the existing challenges of the difficult geo-mining conditions.

Thick seams are found in many countries, e.g., the former USSR, France, Spain, China, former Yugoslavia, Canada and India, etc. In India, over 60% of all known coal reserves are contained in thick seams. Some of these thick seams are nearly 30 m thick. One exceptionally thick seam in Singrauli Coalfield is 162 m thick.

The concept of thick seam varies from country to country, the basis for the lower limit of a thick seam being the thickness up to which a seam could be extracted in one lift (pass) with the available equipment and technology (Table 1).

**Table 1: Thick seam norm in different countries (Das, 1994; Singh, 1997, Deshmukh, 1987)**

| Country | Norm of thickness (maximum height of one lift, m) | Method of working |
|---|---|---|
| Australia | 4.0 | |
| China | 3.75 | Longwall |
| Canada | 4.25 | Room and pillar |
| France | 3.5 | Longwall |
| | 5.0 | Room and pillar |
| Hungary | 4.2 | Longwall |
| | 3.0 | Bord and pillar |
| India | 4.8 | Longwall |
| Japan | 2.25 | Longwall |
| Poland | 4.5 | Longwall |
| | 7.0 | Room and pillar |
| Turkey | | |
| UK | 2.5 | Longwall |
| USA | 1.8 | |
| USSR (Former) | 3.0 | Longwall |
| USSR (Former) | 3.5 | Longwall |
| Yugoslavia (Former) | 6.0 | Chamber and pillar |
| | 4.5 | Longwall |

## 1.1 OBJECTIVE

Determining and analysing the influence of depth and thickness of coal seams on stress distribution over pillars, stooks and ribs after development of pillars and depillaring of thick coal seam through parametric studies by numerical modelling using FLAC 2D software.

**Table 2: Thick Coal Seams in India**

| | |
|---|---|
| Jharia coalfields | • seam IX and X |
| | • Sudamdih colliery |
| Raniganj coalfields | • Perbelia colliery upto |
| | • Jambad and Poidih |
| Singareni collieries | • King seam |
| | • queen seam |
| | • thick seam |
| | • GDK 9,10(Ramagundam) |
| Chirimiri colliery | --- |
| Chinakuri colliery | • Disergh seam, ECL |
| GIDI A mines | • Kranpura coalfields, CCL, Jharkhand |
| Tipong mines | • Assam |

**Table 3:Depth wise Gondwana coal resources of India (Singh, 2007)**

| State | Resource estimate as on 1.1.07 under depth | | | Total Reserve (Mt) |
|---|---|---|---|---|
| | 0-300m | 300-600m | 600-1200m | |
| A P | 7922 | 6514 | 3024 | 17461 |
| Chhattisgarh | 32167 | 8614 | 669 | 41450 |
| Jharkhand | 36998 | 14601 | 3285 | 54884** |
| **Jharia | -------14213--------------- | | 5217 | 19430 |
| Maharashtra | 6789 | 2698 | 183 | 9670 |
| M.P | 12902 | 6727 | 148 | 19777 |
| Orissa | 44636 | 16139 | 1224 | 61999 |
| W Bengal | 12361 | 10975 | 4999 | 28335 |
| Grand Total | 155785 | 80636 | 18749 | 255170 |
| % share | 61.24 | 31.66 | 7.35 | 100 |

# *CHAPTER 2*

# *LITERATURE REVIEW*

# 2. LITERATURE REVIEW

## 2.1 PROBLEMS ASSOCIATED WITH MINING OF THICK COAL SEAMS

Following problems are associated with thick seam mining

1) Difficulty in strata control and its monitoring.
2) Risk of overriding of pillars leading to premature collapse ( in case of bord and pillar workings)
3) Low percentage extraction, usually < 50% when extraction is done by bord and pillar method.
4) Chances of high spontaneous heating because of considerable coal loss in goaf.
5) Heavier support requirement in deep seams and longwall method of working.
6) Difficulty in subsidence control due to high magnitude subsidence.

## 2.2 METHODS OF MINING THICK COAL SEAMS

A general classification of methods of mining thick seams is summarized in Fig. 1. Several modifications/variations to these methods are also tried in different mines.

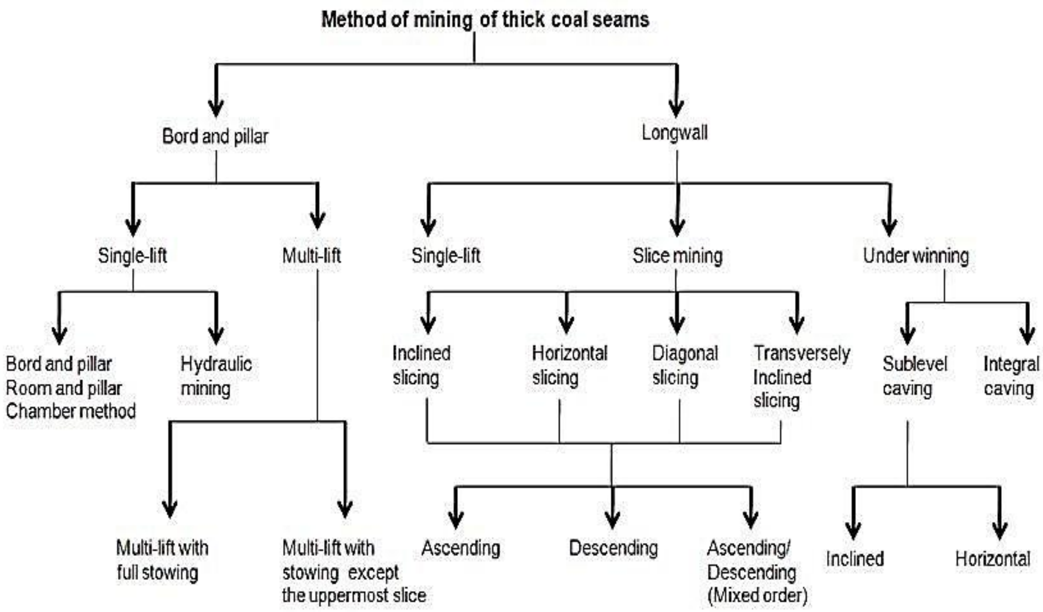


**Fig. 1 General classification of thick seam mining methods (Singh, 1997)**

Single lift mining is generally limited to heights of 4.8m. However, thick seams are normally mined in multi-slices. This is called slice mining, wherein each slice is mined in one pass. Working of each of slice can be either by bord and pillar method or by longwall method. In general bord and pillar method poses greater strata control problems than longwall mining and in thick seam mining, this problem becomes very high. Further heavy coal loss takes place in bord and pillar mining. Therefore longwall mining (with multi slicing) is the preferred method of mining for extraction of coal from thick seams. This is also suitable for mining thick as well as steep seams.

### 2.2.1 Slice Mining

In this method of mining a coal seam is divided into slices of appropriate thickness and each slice is worked in a method similar to that of an entire seam having thickness same as the slice. Coal from the slices can be extracted in ascending, descending or in mixed (both ascending and descending) order (Fig. 2).

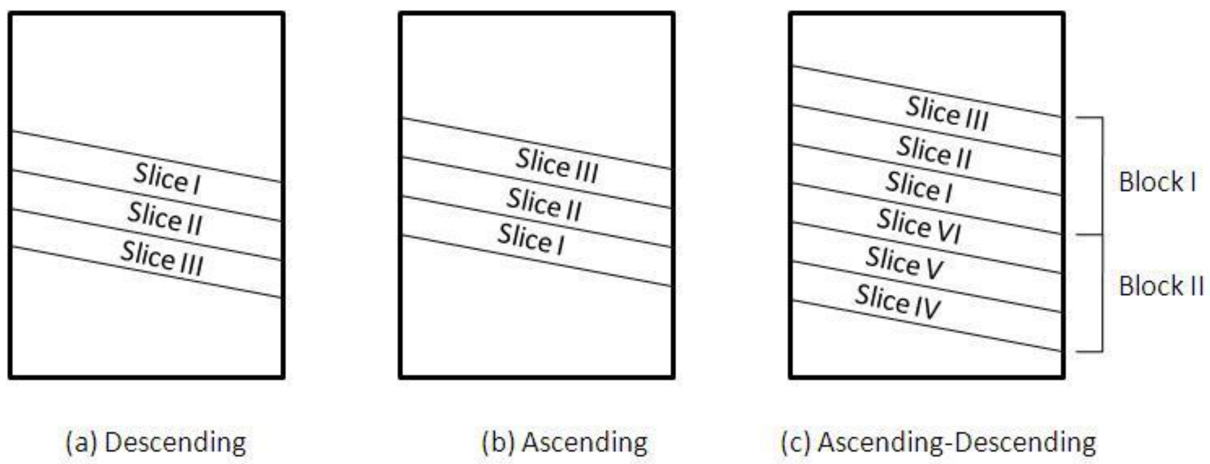


**Figure 2: Different orders of slicing thick coal seams (Singh, 1997)**

**Descending slicing**

Descending slicing can be done with or without stowing. In case of descending slicing with caving, spreading of wire netting is required to make artificial roof to arrest material of the broken goaf of the upper slice and this wire netting serves as the roof for the lower slices; i.e., lower slices are worked below the broken goaf. Stowing is rarely practiced in descending slicing(Fig. 2a).

**Ascending slicing**

In ascending slicing method, the first slice is the bottom most slice which is excavated first. Working of this slice is like working a seam of average thickness. Subsequent slicing is done with stowing, i.e., the upper slices are worked on the filled surface of the bottom slice and therefore ascending slicing cannot be adopted with caving. The last slice can be worked either with stowing or caving (Fig. 2b).

**Mixed order slicing**

In this method coal seam is divided into blocks, each block consisting of a number of slices. The slices in the block are worked in ascending order with stowing, while the blocks are worked in descending order. This method is commonly practiced in horizontal slicing method of thick seam mining (fig 2c).

### 2.2.2 Sublevel Caving

Sublevel caving is applicable to thick seams with caveable roof and soft coal, though by blasting, hard roof can also be caved and hard coal seams can be softened. This system is consists of (i) mining a slice along the roof by normal longwall method with caving with flexible artificial roof laid on coal along the floor of the first slice; (ii) mining of another slice along the floor of the seam, and (iii) taking down the coal parting between the two slices by longhole blasting which is loaded out in a conveyor laid along the floor of the seam. Figure 3shows the method of mining a 6.6 m thick coal seam by sub-level caving. In this method a longwall face takes a slice of 1.8 m along the roof of the seam.

As the face retreats wire netting over steel bands is laid on the floor to form artificial roofing. Some 30 m behind the top face, another longwall face takes a slice of 1.8 m along the floor. The middle coal plate which is usually thicker than the top and bottom slices is mined at a distance of 3.5 m behind the floor longwall face by blasting with long shotholes drilled from under the support of the lower face. The slope of the longwall face of the middle slice should be tilted back with respect to the face by 5-10° from the vertical in the direction of advance of the face. The artificial roof prevents the caved stone from mixing with the coal of the middle plate. The mining in the lower and upper slices can be mechanised by shearers.

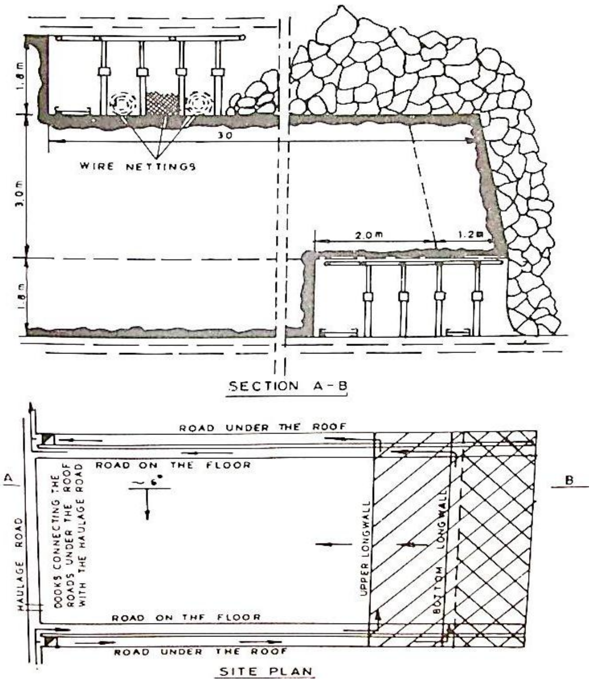


**Figure 3: Diagrammatic layout of mining a thick seam by sub level caving (Kasparek1964) (Singh, 1997)**

While this method is applicable to irregular seam thicknesses, it has a number of drawbacks. They are:

1) Problem of working the face at the roof if the roof of the seam is undulating and fragile.
2) Winning a previous slice cancels the effect of strata pressure. The coal to be undermined is destressed and requires shotfiring to break it.

### 2.2.3 INTEGRAL CAVING

The recent development is full 'Soutirage' working or integrated sublevel caving, *i.e.,* recovering in a single operation all the coal of the seam from a face progressing on the floor (Bieau, 1981; Proust, 1979). Figure illustrates this system of mining. The advantages of this method are:

1. The development costs and the investment in face equipment are well below those required for the method of slices parallel tc stratification, and this advantage is still further increased by the fact that greater seam thicknesses may be worked.

2. Some coal**,** which increases with the increasing seam thickness, is extracted by itself by the strata pressure resulting from the winning operations.
3. Automation of support system, with articulated roof bars known as 'banana.
4. Small number of faces can produce large quantity of coal.
5. Supervision is simpler and, therefore, there is greater efficiency of engineers and overmen, *etc***.**
6. OMS is high say, up to 20 tonnes.

The Problems of 'Soutirage'/Integral caving working-

1. Methane emission: In gassy seams methane emission is increased because of high Assuring taking place in the sublevel coal, above and in advance of the coal face.

As a precaution against gas ignition, in gassy mines 'camouflage* blasting should be done with small charges which will only crack the coal mass. Water infusion at low pressure to produce cracks is also helpful.

2. Risk of fire: Crushed coal left in the goaf may catch fire and as a safeguard the following precautions should be taken:
   i. The working should be done strictly on retreat**.**
   ii. There should be slight dip towards the coal face.
   iii. This helps in goaf control and also permits firedamp or nitrogen (where nitrogen flushing is done) to accumulate in the goaf and make the atmosphere inert.
   iv. Mud flushing of goaf should be done at intervals to seal the goaf.

   v. Leakage of air should be eliminated.
   vi. During holidays the panel should be sealed'.
   vii. Working should be done in panels which can be extracted within the incubation period.

Usually a panel length of 400 m is kept in France.

3. Dust Production: The production of dust due to ‘Soutirage’ may be high and. therefore; adequate counter measures have to be taken against dust production. They are (1) Water infusion from the roadway before the face passes. The infusion holes are drilled from the two gate roads and are arranged in a fan between the floor and the seam. Water infusion increases the natural moisture of coal by 1 to 3%. As a result, the airborne dust is reduced.

4. Heat in the workings: When the depth is high the temperature of the solid coal may be high the solution to the problem is: (i) descensional ventilation in the face, (ii) circulation of a large volume of air. For example, 9 m of air per sec. was circulated at Darcy mine (Proust, 1979). Due to the chimney effect in the sublevel roadways this has the additional advantage of circulating air with relatively low oxygen content at the point where the risk of heating is greatest.

5. Maintenance of gate roads in advance of the face: Road maintenance is difficult due to high convergence. The problem in French mines has been solved particularly by adopting the principle of a double system of roadways in the rock set in the floor of the seam. Sections of the top and bottom roads, driven a very short time before they are used, are linked to this system this length which is relatively small, is inversely proportional to the thickness of the seam.

6. Difficulty in coal face mechanization: There is considerable difficulty in mechanizing coal mining at the face because the roof may be friable and also the coal face is subject to a spill out. Investigations done at the face reveal that:

1) The magnitude of strata movement appears to be clearly linked to the thickness of the seam. Mechanized working of a seam 5-8 m thick is easier than that of a seam 10-15 m thick.
2) Measurements of horizontal expansion show that above the powered supports there is only a more or less deconsolidated mass of coal which tilts progressively 'Soutirage’ working, being pushed by the expansion of the beds which occurs at the coal face, in the non-supported zone, and even in advance of the face.
3) Measurements of vertical expansion show that the roof of the seam follows appreciably the same curve as the crown of the coal face.

### 2.2.4 Blasting Gallery

In this method a seam is developed into panels of about 100 m x 50 m. From the main headings rooms are driven to the full width of the pane land the coal between the rooms is blasted down to the full thickness of the seam and loaded by remotely controlled loaders. Figure shows the layout of a panel for working by sublevel caved rooms and Figure

9illustrates the sublevel caved rooms. The general line of caving forms an angle of 30-45° with the direction of rooms.

The life of the rooms should he kept as short as possible **so** that they do not undergo excessive convergence and the movement of the vehicles is not rendered difficult. The advantage of this system of mining is as follows:

It makes it possible to win narrow panels or larger panels in which the seam conditions (faults dip) arc unsuitable tor a longwall face .It does not require highly experienced workers as a longwall face with 'Soutirage' working .It requires substantially less investments than those required for a longwall with 'Soutirage' working and the equipment required i.e., heading machines or jumbos and LHD can be easily transferred to other roadways if the method is unsuccessful. Thick seams up to 15 m in thickness can be extracted in one pass with percentage extraction ranging from 65 to 85%.The method is highly flexible in that in a district with several units in operation, even if one of the units is under breakdown, production from the district will continue to come. The time required for preparation of a panel in relation to the total life of the panel if less than with other mechanised methods.

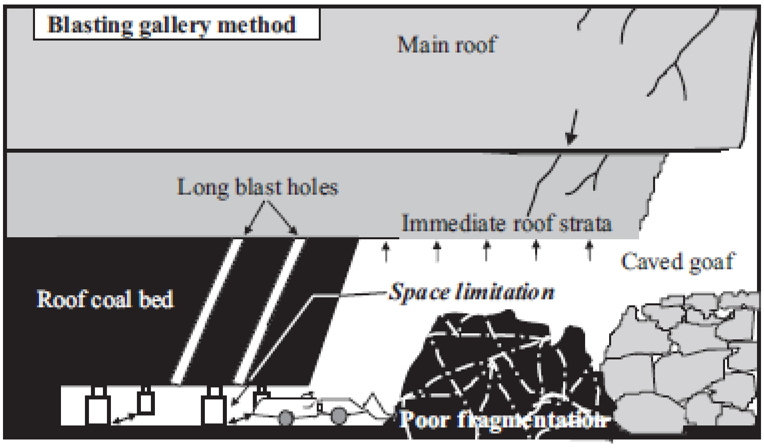


**Figure 4: Blasting gallery method**

### 2.2.5 Thick Seam Mining With Cable Bolting

Location: NCPH mine, Chirimiri, SECL

Method: The seam was parted by graphite band so it was very difficult to control the roof. Hence they drilled large holes in the roof and long cable bolts were installed to hold the graphite roof. The seam was blasted in steps and the coal is extracted.

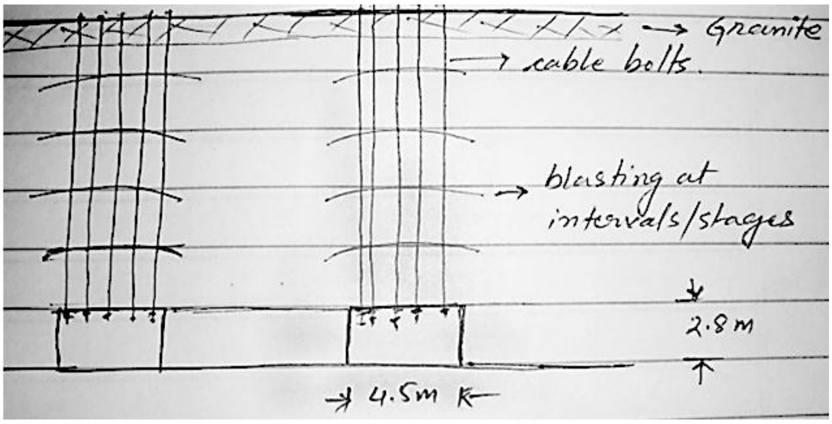


**Figure 5: long cable bolts for stage blasting**

The seam is extensively developed on bord and pillar pattern, pillar size varying from 20 to 30 m centres along the floor upto 3 m height. Depillaring by splitting and slicing was planned by conventional cycle of drilling and blasting and manual loading of coal into the mine car tubs, tubs being hauled by trolley wire locomotives to the surface. After explosions of three panels by 1985, scraper was introduced for face loading. The conventional method was associated with;

a. Unsafe workings due to progressive failure/separation of coal band along the roof because of poor cohesion, side spalling, ineffective support beyond 4.5 m high roof and
b. Fire hazard due to about 60% loss of coal in the goaf.

## 2.3 NUMERICAL MODELLING

*"FLAC* is a two-dimensional explicit finite difference program for engineering mechanics computation. This program simulates the behaviour of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements, or zones, which form a grid that is adjusted by the user to fit the shape of the object to be modelled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. The material can yield and flow and the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Langrangian calculation scheme and the mixed-discretization zoning technique used in *FLAC* ensure that plastic collapse and flow are modelled very accurately. Because no matrices are formed, large two-dimensional

calculations can be made without excessive memory requirements. The drawbacks of the explicit formulation (i.e., small time step limitation and the question of required damping) are overcome to some extent by automatic inertia scaling and automatic damping that do not influence the mode of failure."(FLAC manual,1995)

### 2.3.1 Comparison With Other Methods

How does *FLAC* compare to the more common method of using finite elements for numerical modelling? Both methods translate a set of differential equations into matrix equations for each element, relating forces at nodes to displacements at nodes. Although *FLAC*'s equations are derived by the finite difference method, the resulting element matrices, for an elastic material, are identical to those derived by using the finite element method (for constant strain triangles). However, *FLAC* differs in the following respects:

1) The "mixed discretization" scheme (Marti and Cundall 1982) is used for precise modelling of plastic failure loads and plastic flow. This scheme is believed to be physically more reasonable than the "reduced integration" scheme commonly used with finite elements.
2) The full active equations of motion are used, even when modelling systems are really static. This enables *FLAC* to follow physically unstable processes without numerical distress.
3) An "explicit" solution scheme is used (in contrast to the more usual implicit methods). Explicit schemes can follow arbitrary nonlinearity in stress/strain laws in almost the same computer time as linear laws, whereas implicit solutions can take significantly longer to solve nonlinear problems. Furthermore, it is not necessary to store any matrices, which means that: (a) a large number of elements may be modelled with a modest memory requirement; and (b) a large-strain simulation is hardly more time consuming than a small-strain run, because there is no stiffness matrix to be updated.
4) *FLAC* is robust in the sense that it can handle any constitutive model with no adjustment to the solution algorithm; many finite element codes need different solution techniques for different constitutive models.
5) *FLAC* numbers its elements in a row-and-column fashion rather than in a sequential fashion. For many problems, this method makes it easier to identify elements when specifying properties and interpreting output.

### 2.3.2 Recommended Steps For Numerical Modelling

| | |
|---|---|
| Step 1 | Define the objectives for the model analysis |
| Step 2 | Create a conceptual picture of the physical system |
| Step 3 | Construct and run simple idealized models |
| Step 4 | Assemble problem-specific data |
| Step 5 | Prepare a series of detailed model runs |
| Step 6 | Perform the model calculations |
| Step 7 | Present results for interpretation |

***Step 1: Define the Objectives for the Model Analysis***

The level of detail to be included in a model often depends on the purpose of the analysis. For example, if the objective is to decide between two conflicting mechanisms that are proposed to explain the behaviour of a system, then a crude model may be constructed, provided that it allows the mechanisms to occur. It is tempting to include complexity in a model just because it exists in reality. However, complicating features should be omitted if they are likely to have little influence on the response of the model, or if they are irrelevant to the model's purpose. Start with a global view and add refinement as (and if) necessary.(Flac manual, 1995)

***Step 2: Create a Conceptual Picture of the Physical System***

"It is important to have a clear picture of the problem to provide an initial estimate of the expected behaviour under the imposed conditions. Several questions should be asked when preparing this picture. For example, is it expected that the system could become unstable? Is the predominant mechanical response linear or nonlinear? Are movements expected to be large or small in comparison with the sizes of objects within the problem region? Are there well-defined discontinuities that may affect the behaviour, or does the material behave essentially as a continuum? Is there an influence from groundwater interaction? Is the system bounded by physical structures, or do its boundaries extend to infinity? Is there any geometric symmetry in the physical structure of the system? These considerations will dictate the gross characteristics of the numerical model, such as the design of the model geometry, the types of material models, the boundary conditions, and the initial equilibrium state for the analysis. They will determine whether a three-dimensional model is required, or if a two-dimensional model can be used to take advantage of geometric conditions in the physical system." (Flac manual, 1995)

***Step 3: Construct and Run Simple Idealized Models***

When venerating a physical system for numerical analysis, it is more effective to construct and run simple test models first, before building the detailed model. Simple models should be created at the earliest possible phase in a project to generate both data and understanding. The results can provide further vision into the conceptual picture of the system; Step 2 may need to be repeated after simple models are run. Simple models can reveal inadequacies that can be remedied before any significant effort is invested in the analysis. For example, do the selected material models sufficiently represent the expected behaviour? Are the boundary conditions inducing the model response? The results from the simple models can also help guide the plan for data collection by identifying which parameters have the most influence on the analysis."(Flac manual, 1995)

***Step 4: Assemble Problem-Specific Data***

The types of data required for a model analysis include:

1) details of the geometry
2) locations of geologic structure (e.g., faults, bedding planes, joint sets)
3) material behaviour (e.g., elastic/plastic properties, post-failure behaviour)
4) initial conditions (e.g., in-situ state of stress, pore pressures, saturation); and
5) external loading (e.g., explosive loading, pressurized cavern).

***Step 5: Prepare a Series of Detailed Model Runs***

When preparing a set of model runs for calculation, several aspects, such as those listed below, should be considered.

1) How much time is required to perform each model calculation? It can be difficult to obtain sufficient information to arrive at a useful conclusion if model runtimes are excessive. Consideration should be given to performing parameter variations on multiple computers to shorten the total computation time.
2) The state of the model should be saved at several intermediate stages so that the entire run does not have to be repeated for each parameter variation. For example, if the analysis involves several loading/unloading stages, the user should be able to return to any stage, change a parameter and continue the analysis from that stage. Consideration should be given to the amount of disk space required for save files.

3) Are there a sufficient number of monitoring locations in the model to provide for a clear interpretation of model results and for comparison with physical data? It is helpful to locate several points in the model at which a record of the change of a parameter (such as displacement, velocity or stress) can be monitored during the calculation. Also, the maximum unbalanced force in the model should always be monitored to check the equilibrium or failure state at each stage of an analysis.

***Step 6: Perform the Model Calculations***

"It is best to first make two or more model runs split into separate sections before launching a series of complete runs. The runs should be checked at each stage to make sure that the response is as expected. Once we are assured that the model is performing correctly, several data files can be linked together to run a complete calculation. At any time during a sequence of runs, it should be possible to interrupt the calculation, view the results, and then continue or modify the model as appropriate."(Flac manual,1995)

***Step 7: Present Results for Interpretation***

"The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen, or as output to a hardcopy plotting device. The graphical output should be presented in a format that can be directly compared to field measurements and observations. Plots should clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. The numeric values of any variable in the model should also be readily available for more detailed interpretation by the modeller. We recommend that these seven steps be followed to solve geo-engineering problems efficiently. The following sections describe the application of *FLAC* to meet the specific aspects of each of these steps in this modelling approach."(Flac manual,1995)

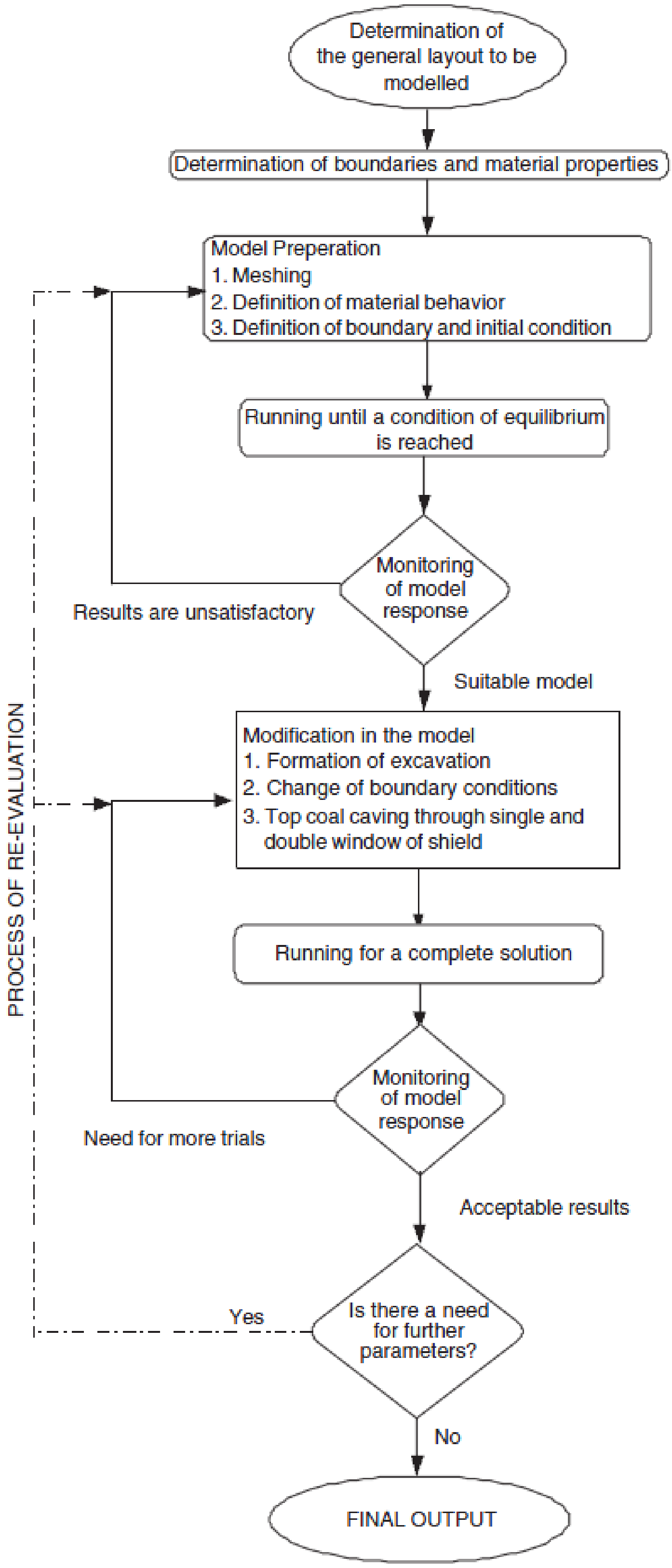


**Figure 6: A general flowsheet of modelling procedure (Yasitli, 2002; Unver and Yasitli, 2002; Itasca, 1997).**

# *CHAPTER 3*

# *METHODOLOGY*

# 3. METHODOLOGY

## 3.1 NUMERICAL MODEL PARAMETERS

Depillaring process in this numerical method includes different stages of division of pillars in to stooks and extraction of stooks upto full seam thickness leaving some ribs in the goaf. For two dimensional representation of full seam extraction in a seam, vertical section with four galleries in an idealised panel was selected (figure 7). A few parameters were kept constant for the model, e.g. width of the pillar, development gallery, split gallery and rib as 20.2 m, 4.8 m, 5 m, and 2.5 m respectively. Pillar size was kept constant at 25 m center to center in accordance with the average size in the field experimental trials. In the first stage of extraction, splits of 5 m width were provided. And the second, third and fourth stages of extraction include high opening upto full seam thickness with formation of ribs in the goaf. Stress conditions in these conditions were studied in numerical models.

About 24 numerical models with different configuration of openings representing the range of parameters in the field experiment trials are used. Variables of the parametric studies for stress analysis are; seam thickness in the range of 5 to 11 m at an interval of 2 m, and depth cover in the range of 150-900 m at an interval of 150 m.

## 3.2 THE FOLLOWING SEQUENCE OF THE PILLAR DEVELOPMENT AND EXCAVATIONS WERE SIMULATED FOR ALL THE ABOVE PARAMETERS:

1) Development of pillars (25 m center to center) (figure 7).
2) Splitting of three rows of pillars (figure 8).
3) Extraction of a row of pillars with a single rib inside the goaf (figure 9).
4) Extraction of two rows of pillars with two ribs inside the goaf (figure 10).
5) Extraction of two and a half row of pillars with two ribs inside the goaf (figure 11).
6) Extraction of two and a half row of pillars with a single rib inside the goaf (figure 12).

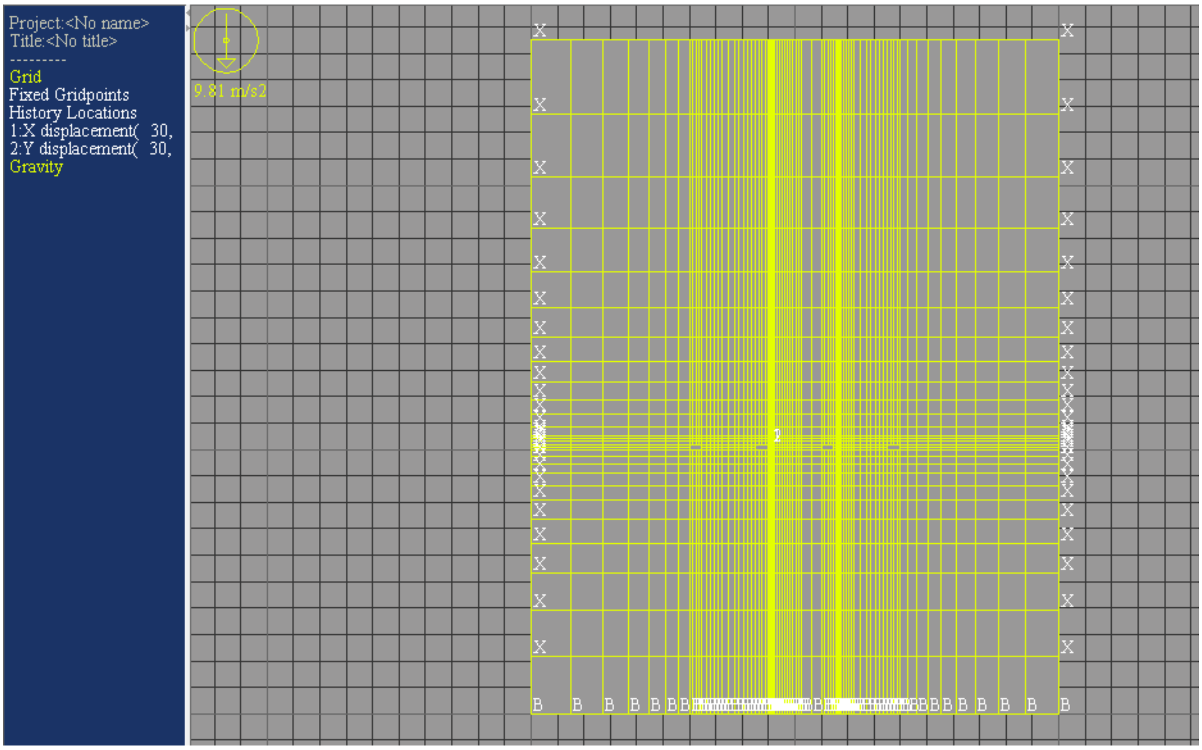


**Figure 7: development of three pillars (25 m center to center) with four galleries (3x4.8 m)**

The coal elements in the panel are small; 0.5 m in the ribs and 1 m in the pillar. Each represents 2 $m^2$ area of the seam as maximum size. To reduce the time to solve the model, the dimensions of the mesh elements increase geometrically from the model to its outer edges. The model has plate elements with nodes as shown in the figure 7. The problem domain consist of approximate boundary conditions and grid pattern for 150 m depth cover with development into extraction in plain strain conditions with Mohr Coulomb material. Young's modulus and Poisson's ratio of the coal elements was 2 GPa and 0.25 respectively, while the corresponding properties for the sandstone elements was 5 GPa and 0.25 respectively. Cohesion, density, tensile strength and angle of internal friction for the coal are assumed as 2.6 MPa, 1.4 $g/cm^3$, 1.85 Mpa and $30^o$ respectively.

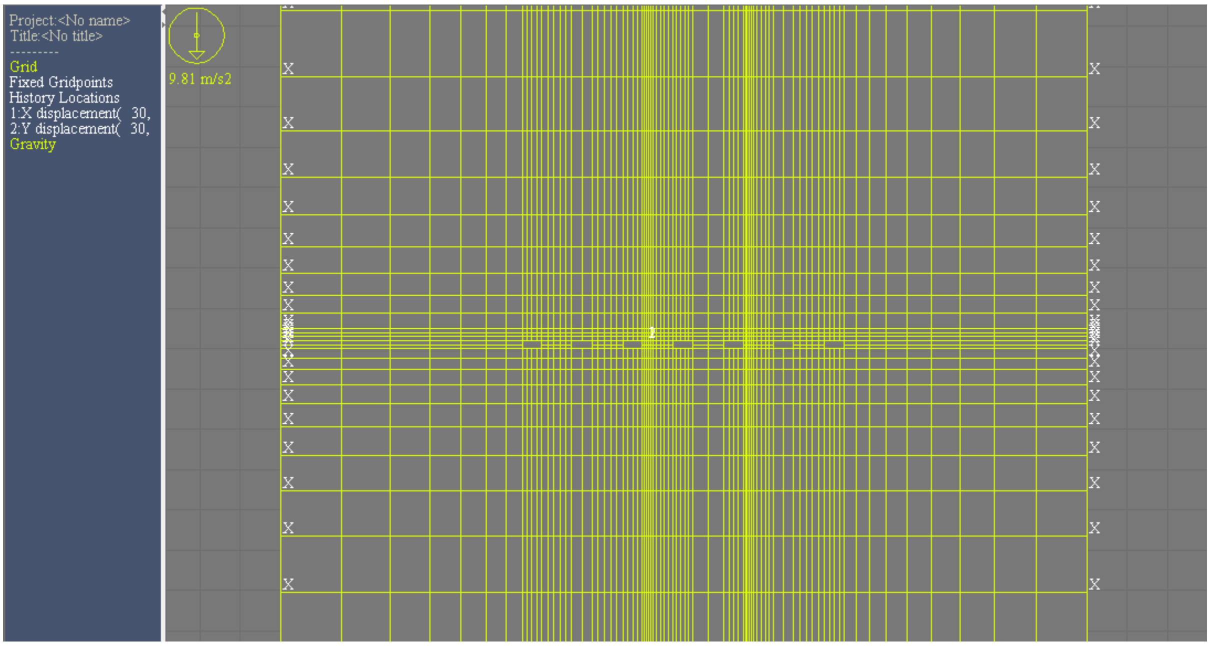


**Figure 8: Splitting of three pillars**

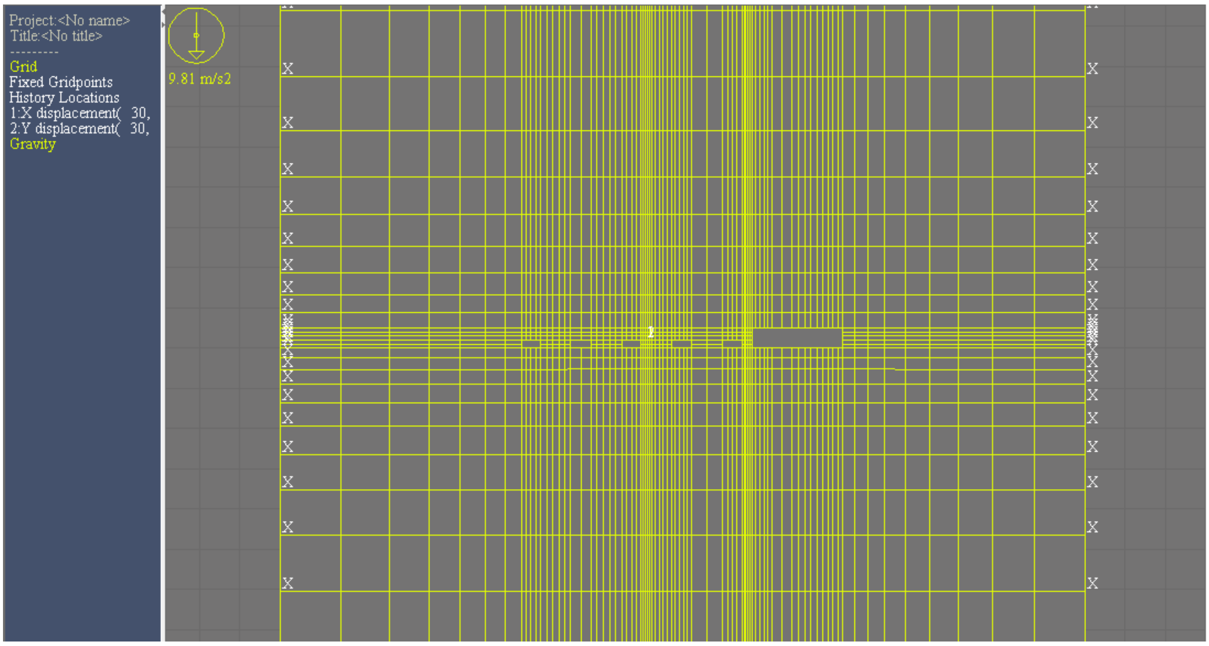


**Figure 9: Extraction of a row of pillars with a single rib inside the goaf**

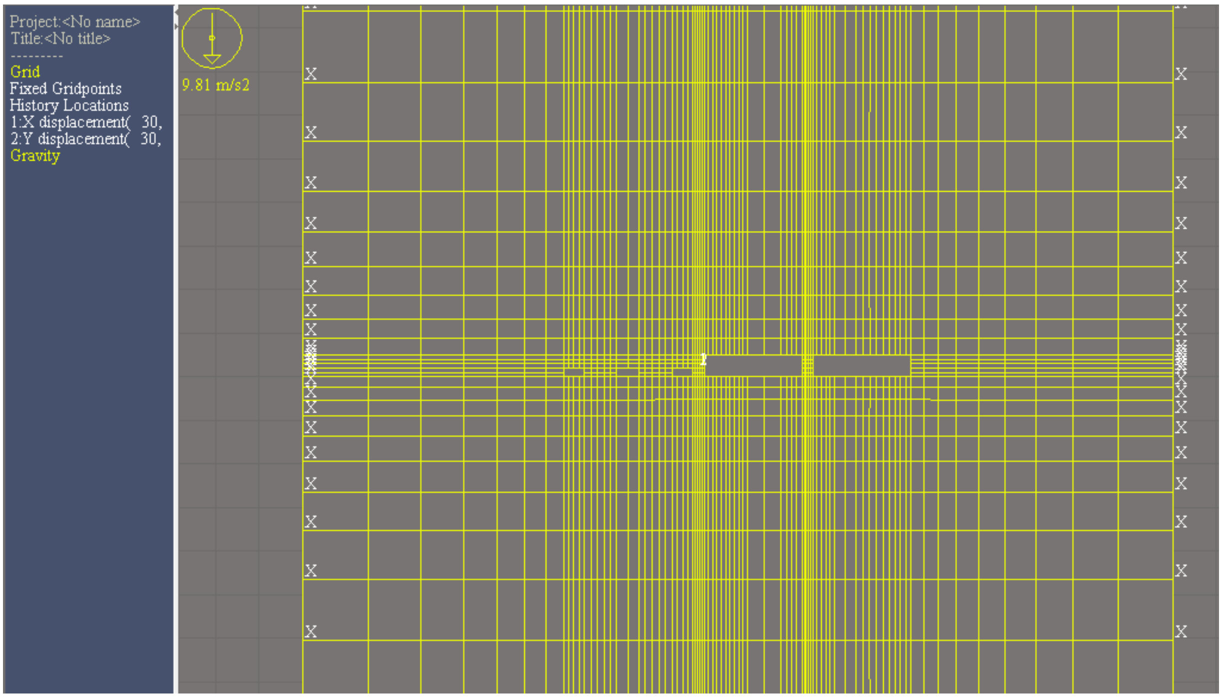


**Figure 10: Extraction of two rows of pillars with two ribs inside the goaf**

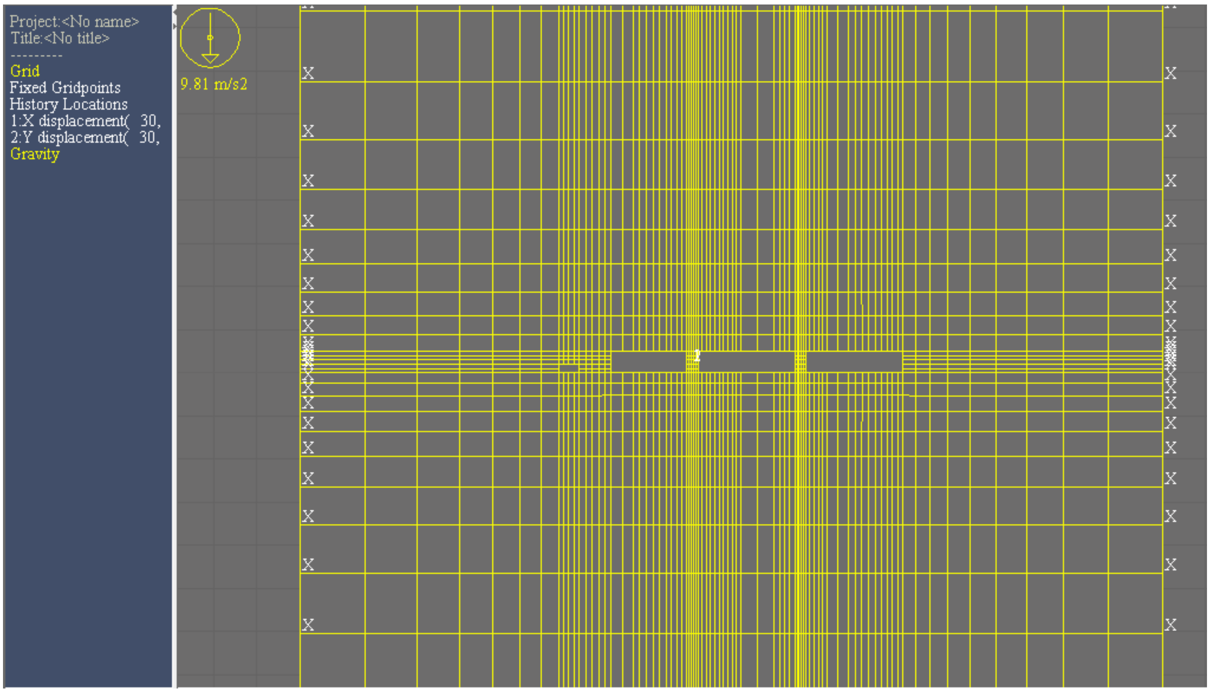


**Figure 11: Extraction of two and a half row of pillars with two ribs inside the goaf**

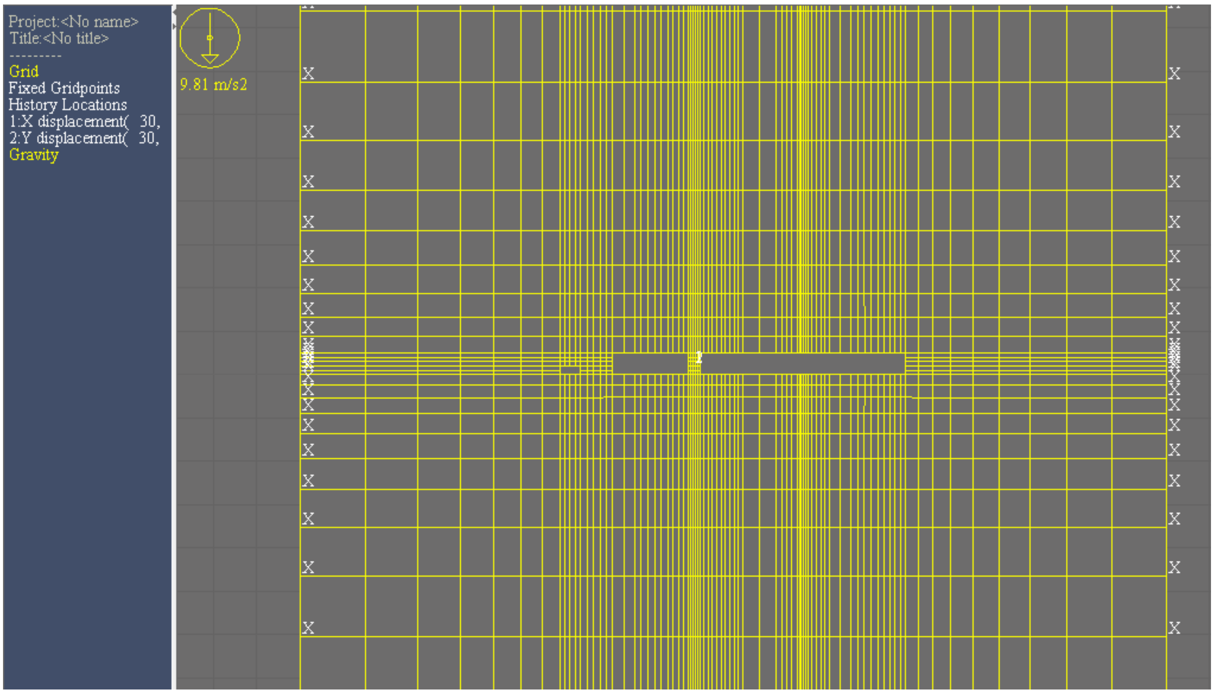


**Figure 12: Extraction of two and a half row of pillars with a single rib inside the goaf**

The top of model is free to move in any direction, and the bottom edge of the model is restricted from moving vertically. Roller type boundary conditions for all the models are placed along two edges of the models. In the absence of the in-situ stress measurement in the coal field, the following norms were adopted for estimation of in-situ stress field prior to the excavation of the area.

Vertical stress $= \rho$ x H

Horizontal stress $= 3.75 + 0.015$ H

Where,

$\rho$ = specific weight of the overlying rock mass and

H = depth cover

The model has induced internal stress that simulates gravity loading. To generate pre-mining conditions before adding the mine openings to the input, the model goes through an initial analysis to generate the insitu stresses. Gravitational and horizontal loading are forced on the other two surfaces in order to account for insitu stresses. The displacements are reset to zero and the mine openings are added. The model is then reanalysed to obtain the final stress distributions over the structures.

# *CHAPTER 4*

# *RESULTS AND ANALYSIS*

# 4. RESULTS AND ANALYSIS

## 4.1 RESULTS

### 4.1.1 Results For Maximum Stress Over Pillar Stook And Rib (After Extraction Of Two And Half Pillars)

**Table 4: Maximum vertical stress over pillar, stook and rib for different seam thickness and depth as per numerical model**

| Sr. No. | Depth (m) | Thickness (m) | Max. Stress (Pillar) (Mpa) | Max. Stress** (Stook) (Mpa) | Max. Stress** (Rib) (Mpa) |
|---|---|---|---|---|---|
| 1 | 150 | 5 | 5 | 10 | 8 |
| 2 | 300 | 5 | 10 | 20 | 7.5 |
| 3 | 450 | 5 | 17.5 | 35 | 5 |
| 4 | 600 | 5 | 20 | 40 | 0 |
| 5 | 750 | 5 | 25 | 60 | 0 |
| 6 | 900 | 5 | 35 | 70 | 0 |
| 7 | 150 | 7 | 5 | 10 | 6 |
| 8 | 300 | 7 | 10 | 25.5 | 7.5 |
| 9 | 450 | 7 | 17.5 | 35 | 10 |
| 10 | 600 | 7 | 22.5 | 40 | 5 |
| 11 | 750 | 7 | 25 | 40 | 0 |
| 12 | 900 | 7 | 30 | 50 | 0 |
| 13 | 150 | 9 | 5 | 8 | 6 |
| 14 | 300 | 9 | 10 | 20 | 7.5 |
| 15 | 450 | 9 | 10 | 25 | 5 |
| 16 | 600 | 9 | 20 | 25 | 0 |
| 17 | 750 | 9 | 25 | 30 | 0 |
| 18 | 900 | 9 | 30 | 30 | 0 |
| 19 | 150 | 11 | 5 | 8 | 6 |
| 20 | 300 | 11 | 10 | 17.5 | 5 |
| 21 | 450 | 11 | 15 | 15 | 5 |
| 22 | 600 | 11 | 20 | 15 | 5 |
| 23 | 750 | 11 | 25 | 10 | 0 |
| 24 | 900 | 11 | 30 | 10 | 0 |

**Table 5: Results for depth vs maximum stress in pillars for various depths**

| Depth | Max. Stress (Pillar 5m) MPa | Max. Stress (Pillar 7m) MPa | Max. Stress (Pillar 9m) MPa | Max. Stress (Pillar 11m) MPa |
|---|---|---|---|---|
| 150 | 5 | 5 | 5 | 5 |
| 300 | 10 | 10 | 10 | 10 |
| 450 | 17.5 | 17.5 | 10 | 15 |
| 600 | 20 | 22.5 | 20 | 20 |
| 750 | 25 | 25 | 25 | 25 |
| 900 | 35 | 30 | 30 | 30 |

**Table 6: Results for depth vs maximum stress in stooks for various depths**

| Depth | Max. Stress** (stook 5m) MPa | Max. Stress** (stook 7m) MPa | Max. Stress** (stook 9m) MPa | Max. Stress** (stook 11m) MPa |
|---|---|---|---|---|
| 150 | 10 | 10 | 8 | 8 |
| 300 | 20 | 25.5 | 20 | 17.5 |
| 450 | 35 | 35 | 25 | 15 |
| 600 | 40 | 40 | 25 | 15 |
| 750 | 60 | 40 | 30 | 10 |
| 900 | 70 | 50 | 30 | 10 |

**Table 7: Results for depth vs maximum stress in ribs for various depths**

| Depth | Max. Stress** (rib 5m) MPa | Max. Stress** (rib 7m) MPa | Max. Stress** (rib 9m) MPa | Max. Stress** (rib 11m) MPa |
|---|---|---|---|---|
| 150 | 8 | 6 | 6 | 6 |
| 300 | 7.5 | 7.5 | 7.5 | 5 |
| 450 | 5 | 10 | 5 | 5 |
| 600 | 0 | 5 | 0 | 5 |
| 750 | 0 | 0 | 0 | 0 |
| 900 | 0 | 0 | 0 | 0 |

** = Stresses on stooks or ribs after extraction of two and half pillars

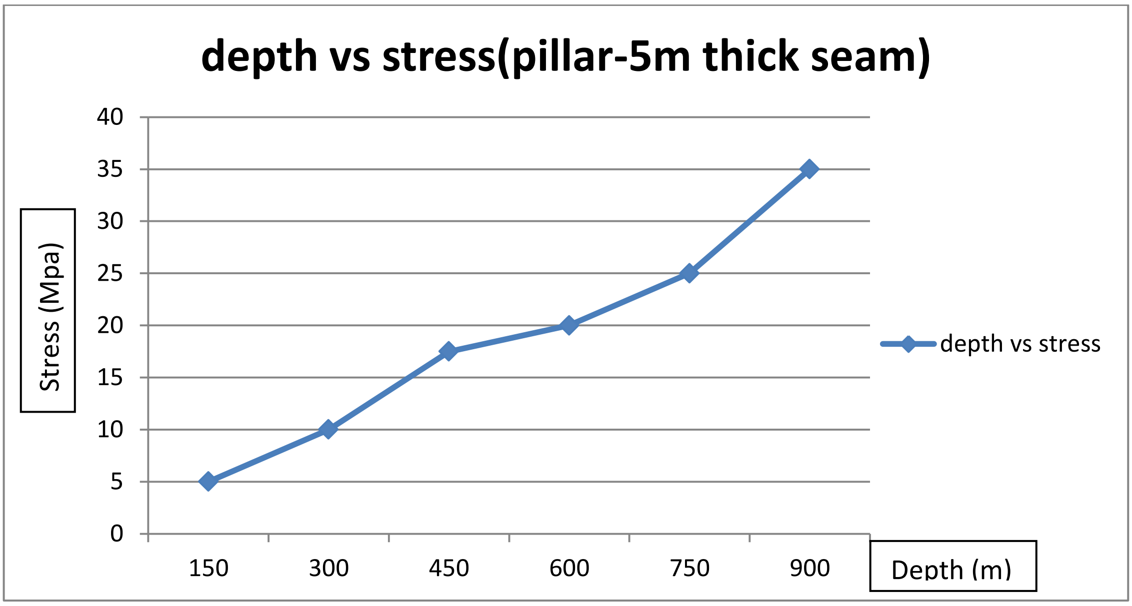


**Figure 13: Stresses on pillars after development work in 5m Thick Seams**

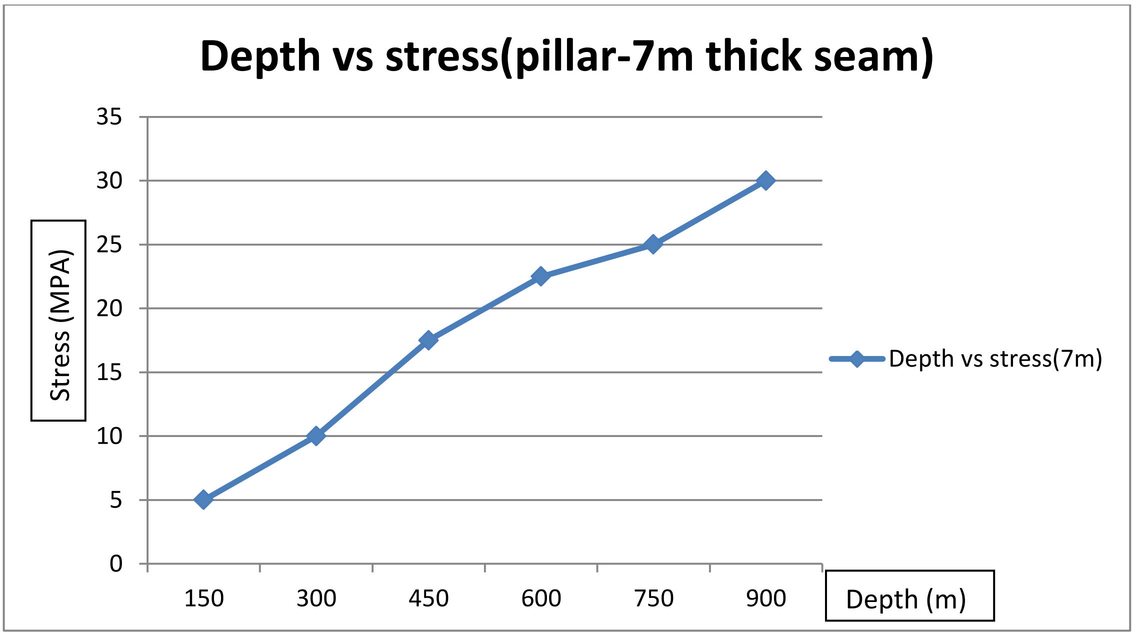


**Figure 14: Stresses on pillars after development work in 7m thick seam**

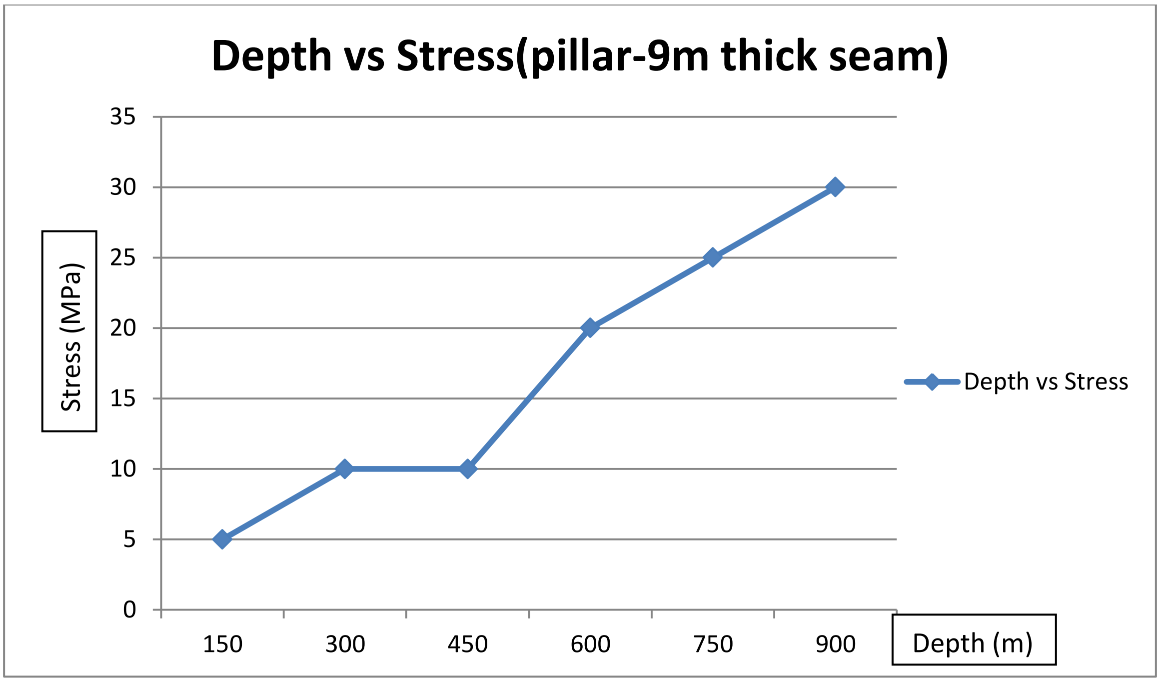


**Figure 15: Stresses on pillars after development work in 9m thick seams**

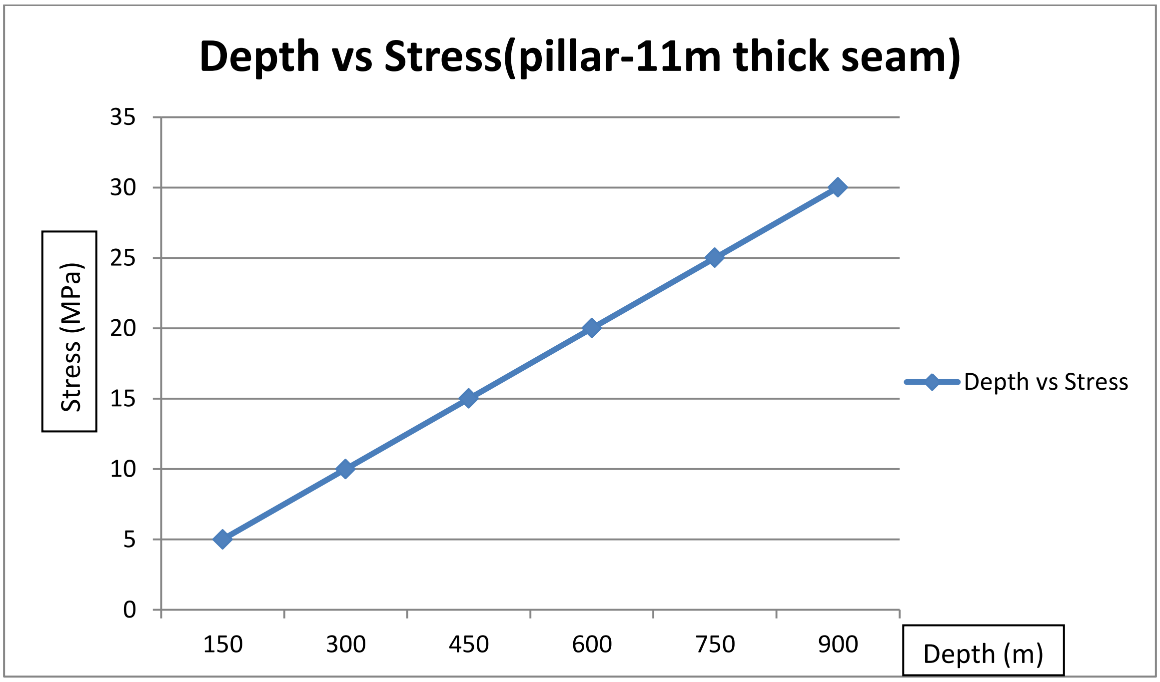


**Figure 16: Stresses on pillars after development work in 11m thick seams**

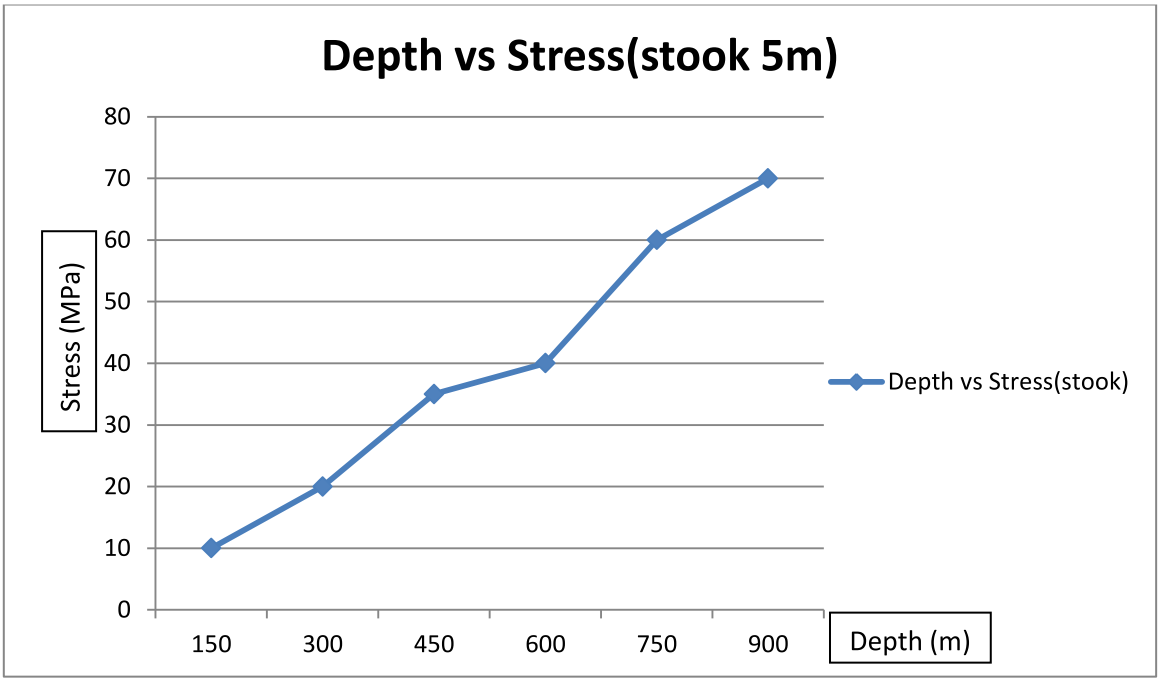


**Figure 17: Stresses on stooks after extraction of two and half pillars in 5m thick seams**

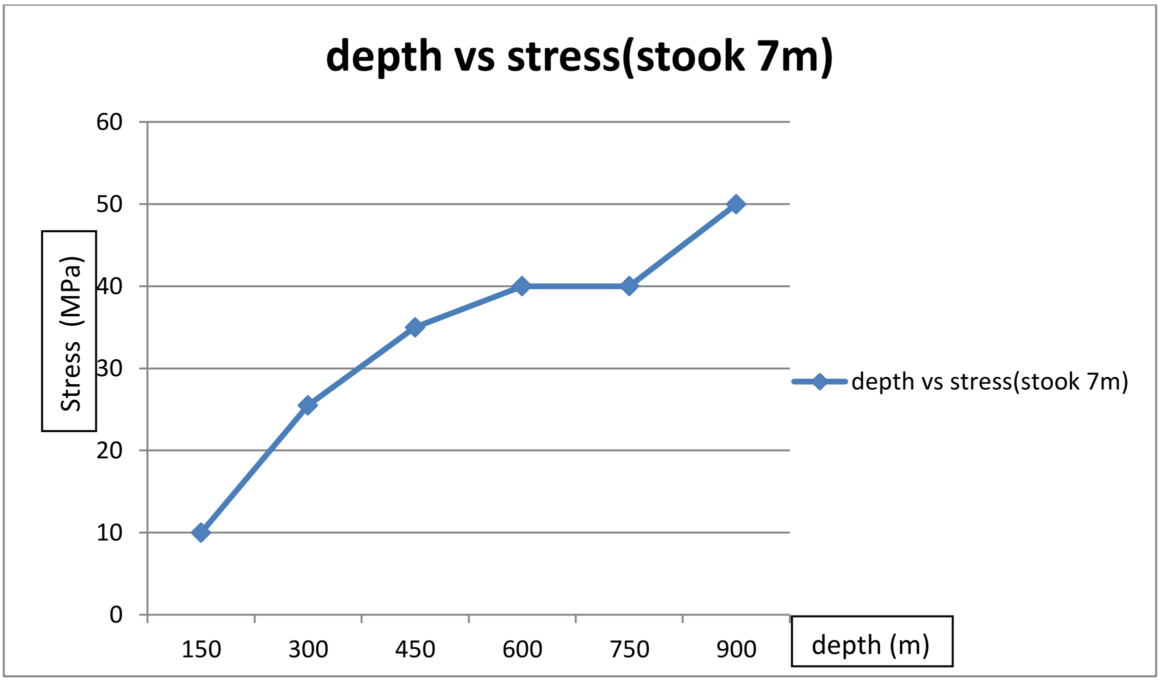


**Figure 18: Stresses on stooks after extraction of two and half pillars in 7m thick seams**

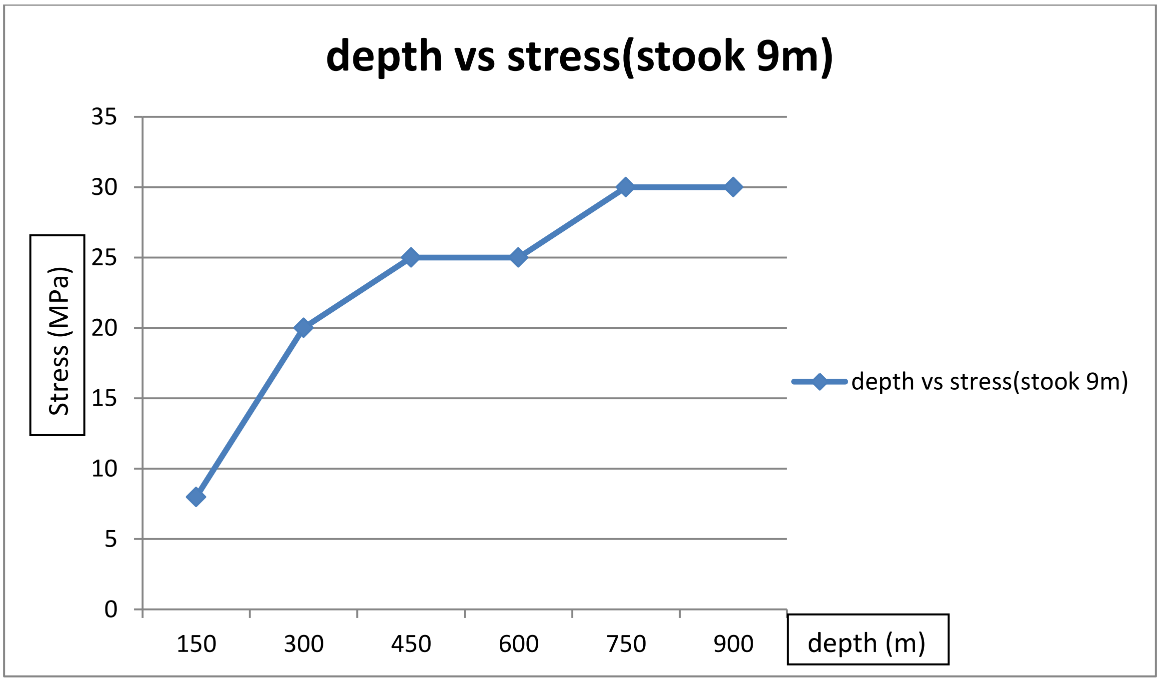


**Figure 19: Stresses on stooks after extraction of two and half pillars in 9m thick seams**

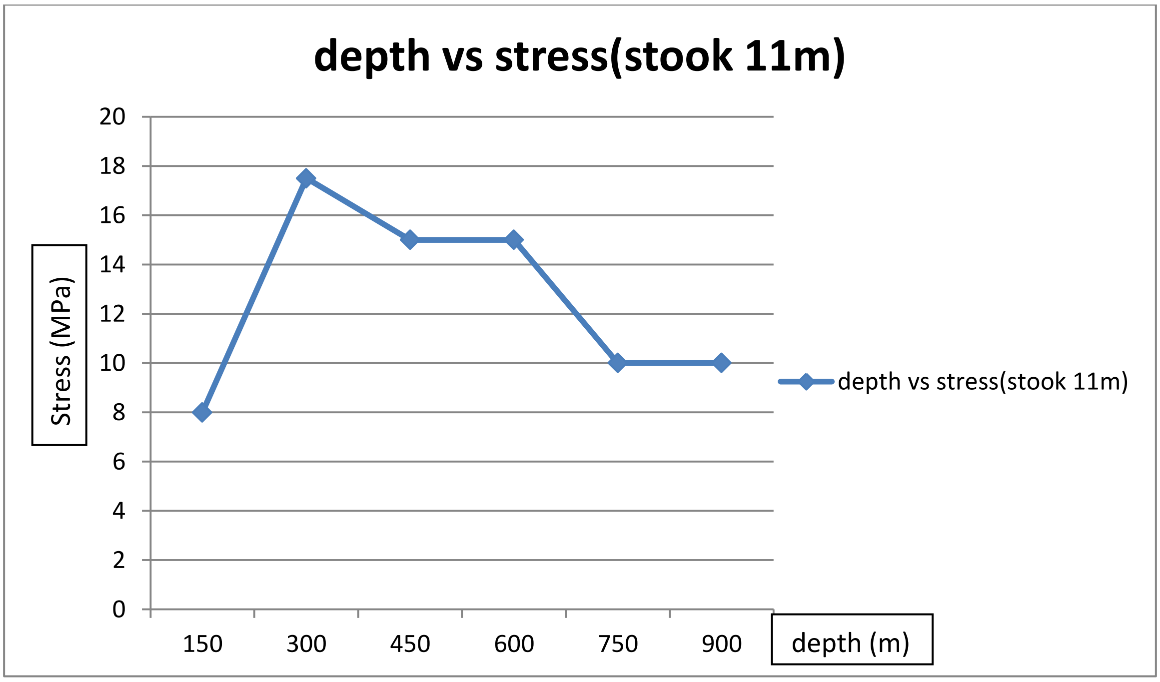


**Figure 20: Stresses on stooks after extraction of two and half pillars in 9m thick seams**

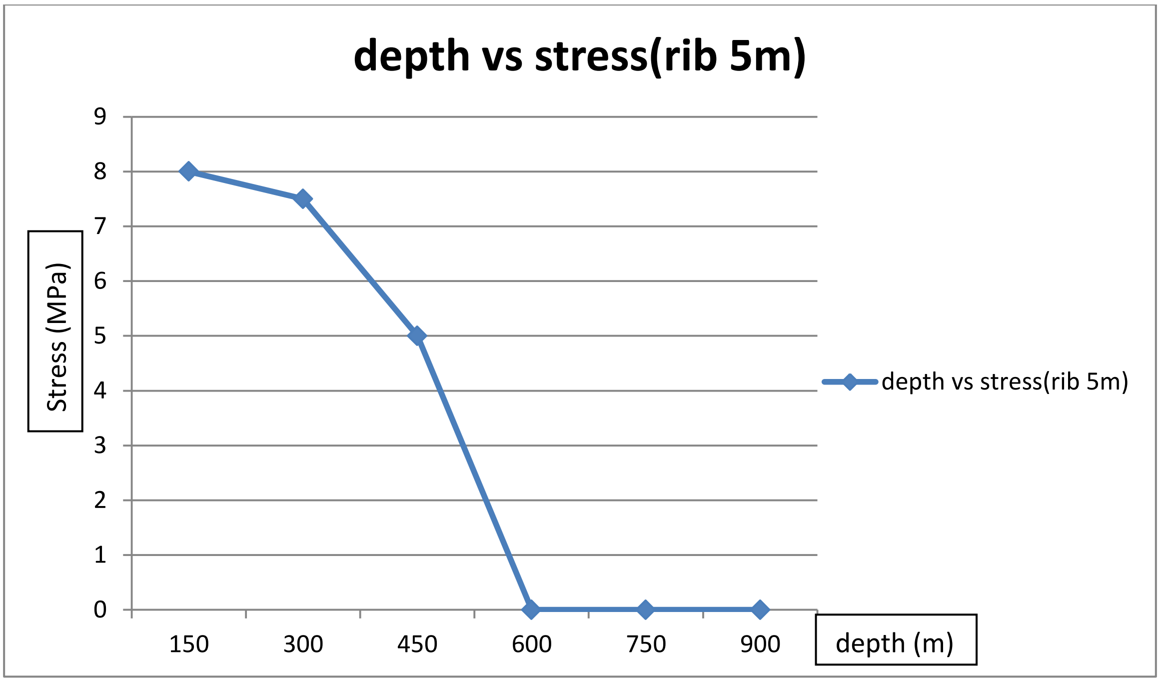


**Figure 21: Stresses on ribs after extraction of two and half pillars in 5m thick seams**

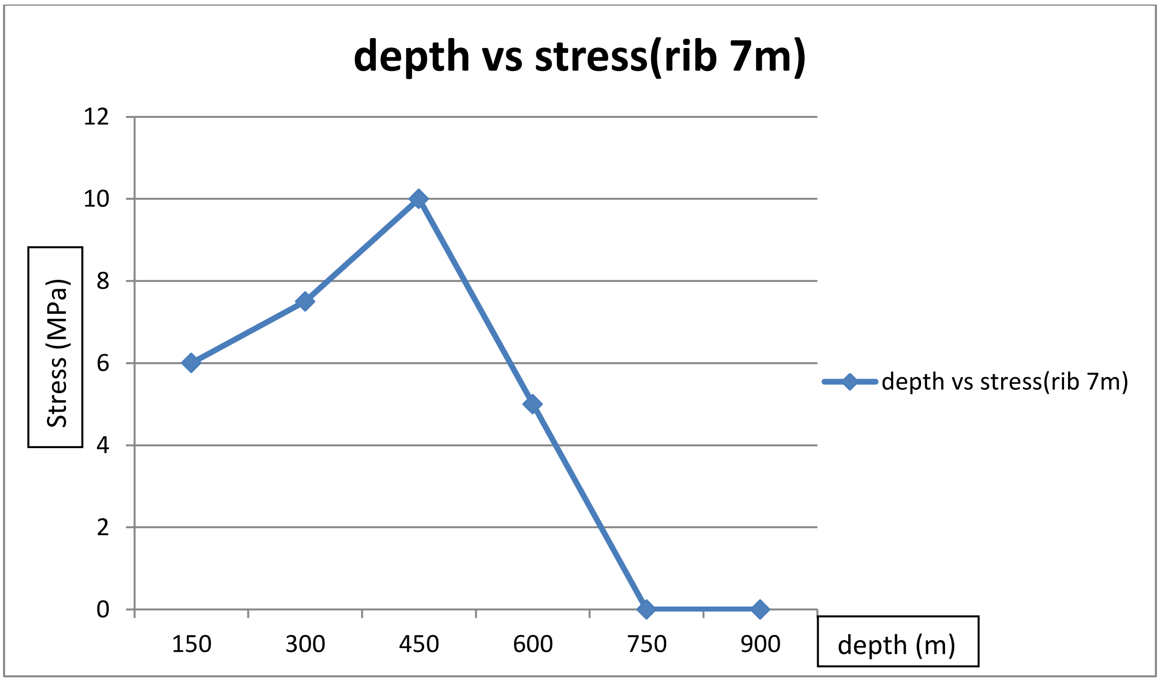


**Figure 22: Stresses on ribs after extraction of two and half pillars in 7m thick seams**

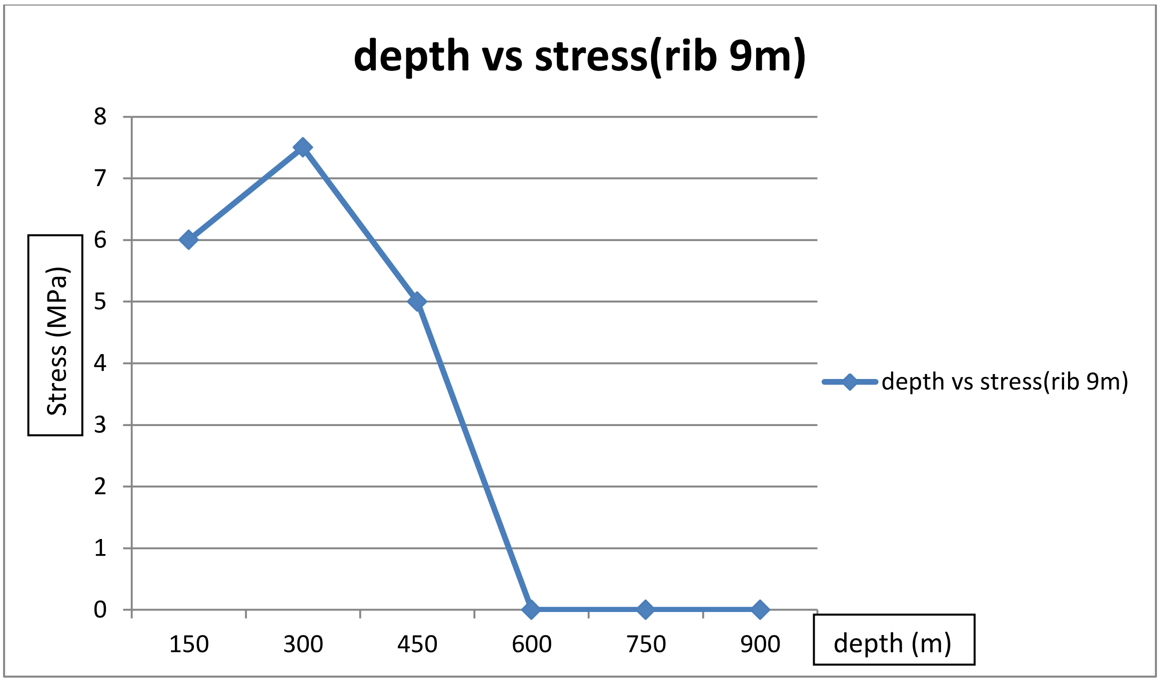


**Figure 23: Stresses on ribs after extraction of two and half pillars in 9m thick seams**

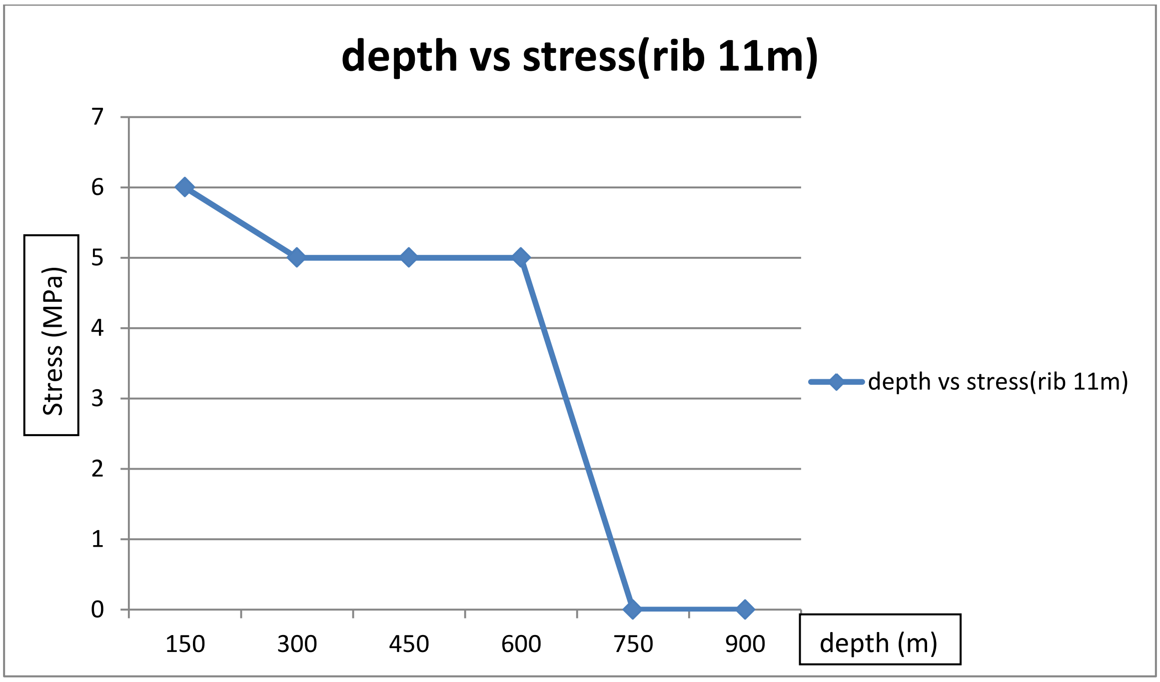


**Figure 24: Stresses on ribs after extraction of two and half pillars in 11m thick seams**

### 4.1.2 Numerical Model Result Plots For Some Typical Conditions

1) Stress results for 7m thick seam at shallow depth (150 m) for both development stage and stage after excavation of two and half pillar-

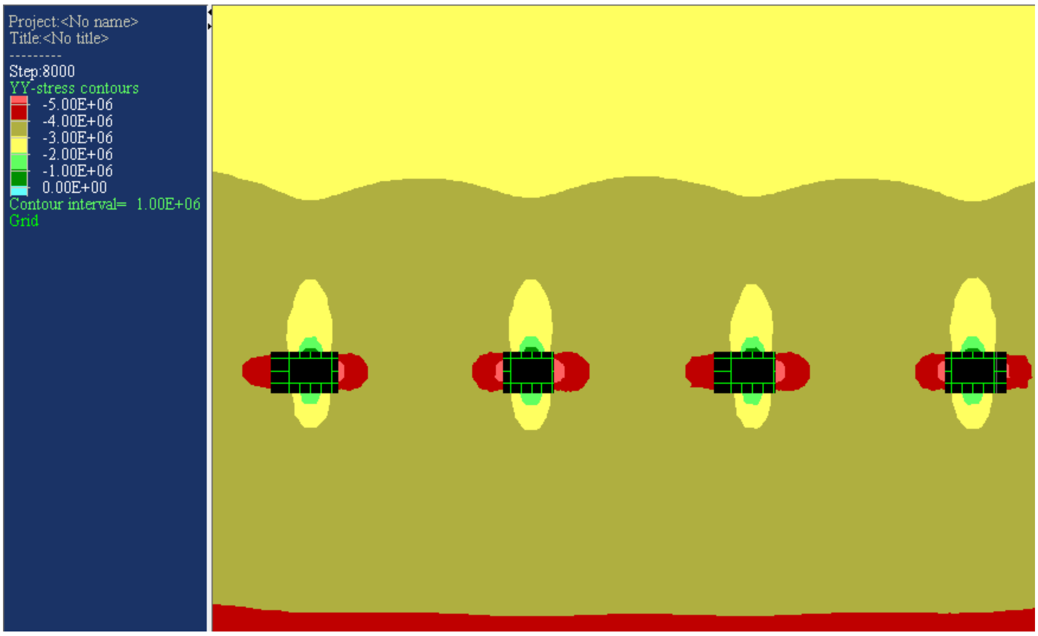


**Figure 25: Stress result plot for developed pillar at 150m depth for 7m thick seam**

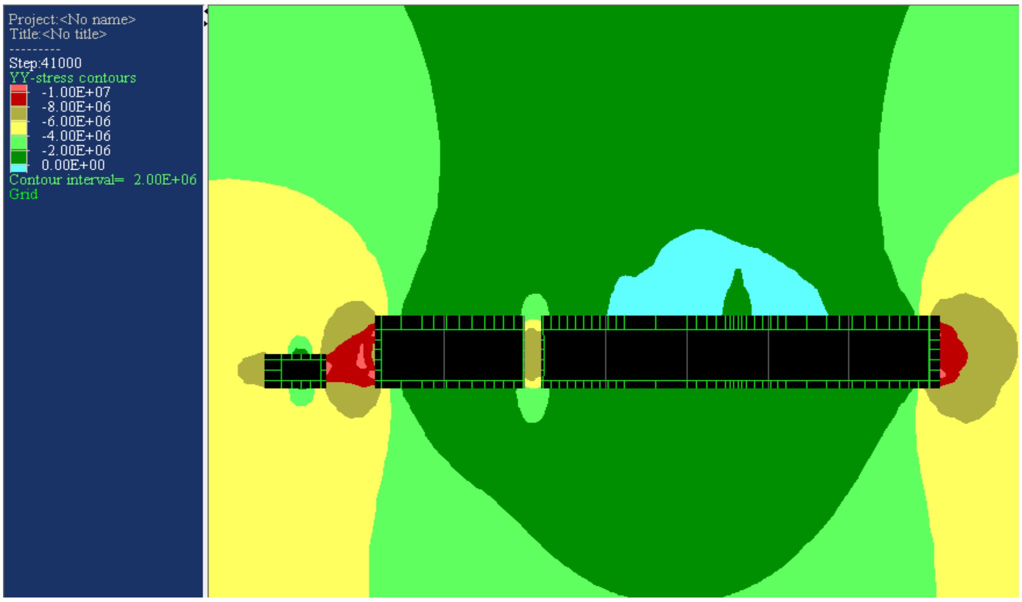


**Figure 26: Stress results plot for stook and rib after extraction of two and half pillar at150m depth**

2) Stress results for 7m thick seam at moderate depth(450 m) for both development stage and stage after excavation of two and half pillar

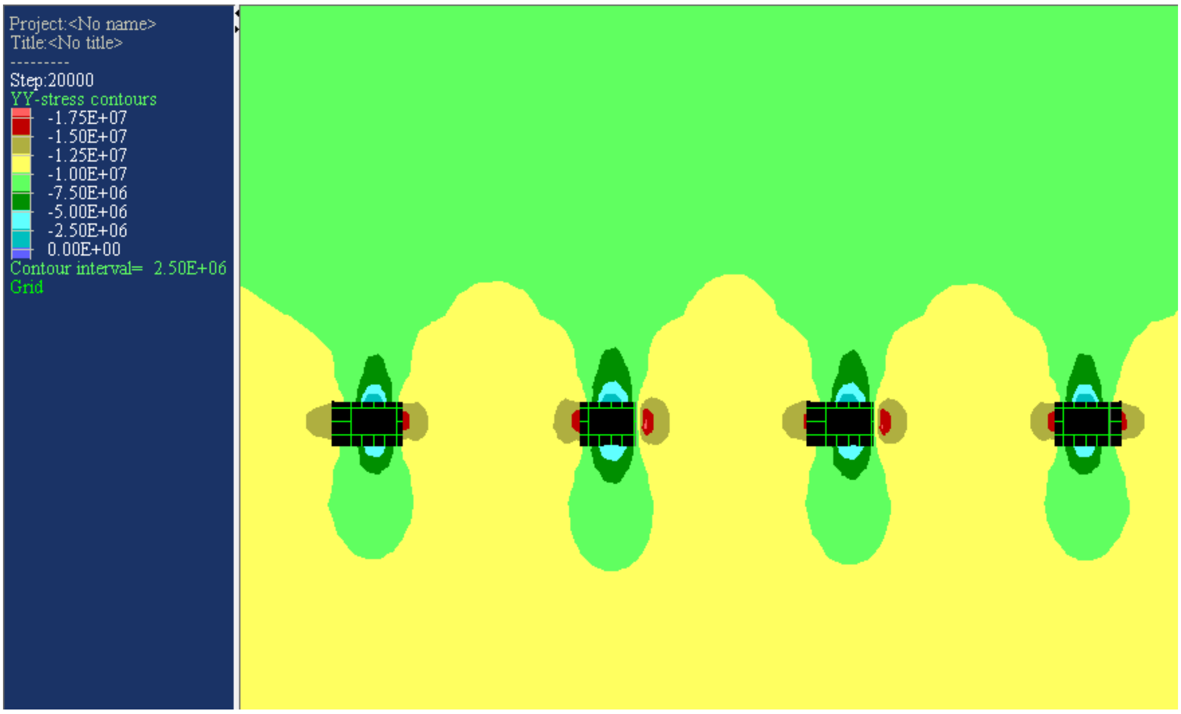


**Figure 27: Stress result plot for developed pillar at 450m depth for 7m thick seam**

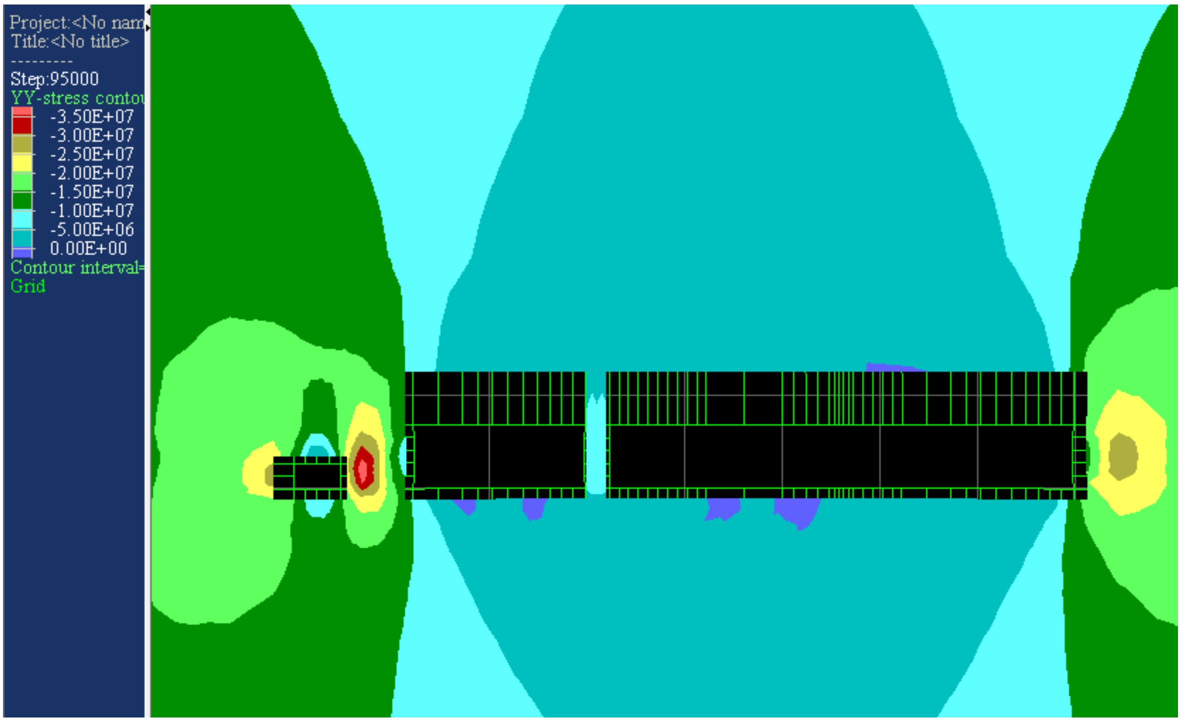


**Figure 28: Stress results plot for stook and rib after extraction of two and half pillar at 450m depth**

3) Stress results for 7m thick seams at deeper depths (900 m) for both development stage and stage after excavation of two and half pillar

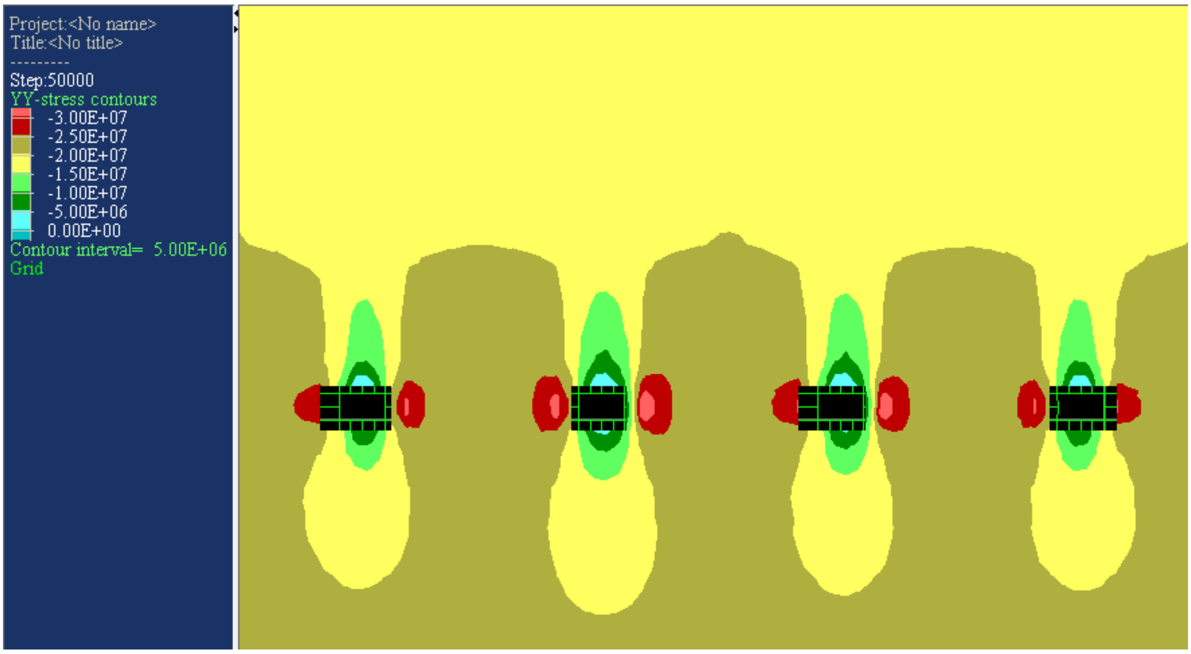


**Figure 29: Stress result plot for developed pillar at 900m depth for 7m thick seam**

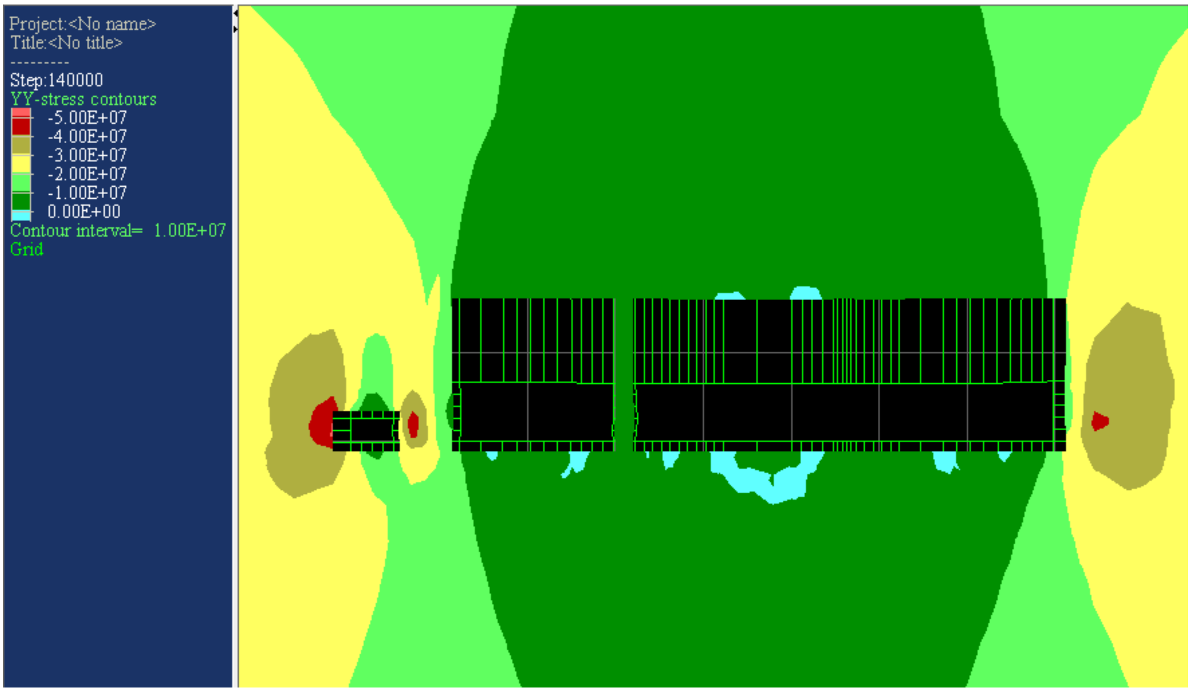


**Figure 30: Stress results plot for stook and rib after extraction of two and half pillar at 900m depth**

## 4.2 ANALYSIS

### 4.2.1 Analysis Of Vertical Stresses Over Pillars, Stooks And Ribs At Various Depths

1. Analysis of stress over 5 m thick seam
   i.) On pillars- There was a uniform increase in stress over the pillars with respect to depth. It shows as the depth increases stress over pillar increases. The minimum and maximum stresses were 5 Mpa and 35 Mpa at a depth of 150m and 900m respectively.
   ii.) On stooks- A proportional increase in stress over stook was observed with respect to increase in depth. The minimum and maximum stresses were found to be 10 Mpa and 70 Mpa at a depth of 150m and 900m respectively.
   iii.) On ribs- The rib got yielded at the minimum study depth only that is 150m. The maximum stress it could bear was found to be 8 Mpa.
2. Analysis of stress over 7 m thick seam
   i.) On pillars- As the depth increases vertical stresses on the pillar increases. The minimum and maximum stresses were 5 Mpa and 30 Mpa at 150m and 900m respectively.
   ii.) On stooks- Increase in vertical stress was observed with increase in depth of the workings. Minimum and maximum stresses were 10 Mpa and 50 Mpa respectively.
   iii.) On ribs- Maximum stress a rib can bear was found to be 10 Mpa at 300m depth. After this depth the rib failed.
3. Analysis of stress over 9 m thick seam
   i.) On pillars- Increase in stress on pillars was found to be increasing proportionally with increase in depth. Minimum and maximum stress was found to be 5 Mpa and 30 Mpa at 150m and 900 m depths respectively.
   ii.) On stooks- Increase in stress on stooks was observed with increase in depth but it was not directly proportional. The minimum and maximum stresses were 8 Mpa and 30 Mpa at 150m and 900m respectively.
   iii.) On ribs- Maximum stress a rib can bear in 9m thick seam was found to be 7.5 Mpa at 300m depth.

4. Analysis of stress over 11 m thick seam
    i.) On pillars- Increase in stress on pillars was directly proportional to the increase in depth. The minimum and maximum stress was found to be 5Mpa and 30Mpa.
    ii.) On Stooks- The minimum and maximum stress was found to be 8Mpa and 17.5Mpa at 150m and 300m depth respectively. After that the value showed a decreasing pattern showing failure of the stook.
    iii.) On ribs- The rib reached its maximum value at 150m depth only and max stress was 6Mpa.

### 4.2.2 Analysis Of Effect Of Thickness Of Seam On Stress Behaviour Over Pillars, Stooks And Ribs

1. On Pillars- From the model results it was found that thickness of the seam does not have any effect on the stress behaviour of the pillars after development work. The stress values are same at every depth cover taken under consideration. The minimum and maximum stress on pillar was found to be 5Mpa and 30Mpa for every depth and thickness of the seam.
2. On Stooks- Parametric studies through the numerical models indicated decreased vertical stress over the stooks with increasing height of the extraction at the depth covers in the range of 150-900 m. The variation of stress concentration over stooks was in range of 8-70 Mpa for extraction height of 5m, 7m, 9m and 11m. Though the stress coming was less the stooks were getting yielded very soon due to increase in height of the stook and increase in height to width ratio.
3. On ribs- The model indicated decreased value of stress in ribs with increasing seam thickness at the depth cover in the range of 150-900 m. Maximum stress concentration over ribs for 5m,7m, 9m and 11m seam thickness was in the range of 6-10 Mpa. The ribs were observed to be failing early as the extraction height increased i.e. increase in seam thickness. This is also due to increase in height of the rib and increase in width to length ratio.

# *CHAPTER 5*

# *CONCLUSIONS AND SUGGESTIONS*

# 5. CONCLUSIONS and SUGGESTIONS

## 5.1 CONCLUSION

Vertical induced stresses over pillars/stooks/ribs were guesstimated in extraction of pillars in a 5 to 11 m thick coal seam. Influence of depth cover and height of extraction that is thickness of seam was also studied through the two dimensional finite difference code-FLAC. Based on the field and numerical model results, the following conclusions are drawn:

1) From the model results it was found that thickness of the seam does not have any effect on the stress behaviour of the pillars after development work.
2) Parametric studies through the numerical models indicated decreased vertical stress over the stooks with increasing height of the extraction at the depth covers in the range of 150-900 m.
3) Though the stress coming was less the stooks were getting yielded very soon due to increase in height of the stook and increase in height to width ratio.
4) The model indicated decreased value of stress over ribs with increasing seam thickness at the depth cover in the range of 150-900 m. But the ribs were observed to be failing early as the extraction height increased.
5) This study also proves that as the height of extraction increases the structures gets yielded very early and fails soon. Though initially stress over them is less.

## 5.2 SUGGESTIONS

Numerical modelling still has a long way to go and extremely large potential for the future. In particular we are at a stage where we can start to model in detail in 3 dimensions, where we have been restricted to 2 dimensional cross sections until recently. This will help to model such things as rock burst events, like that which led to a fatality in various mines, and the design of support systems at junctions and face ends, where a majority of roof falls still tend to occur. We also need to be able to investigate the effect of increasing the spacing between rows of rock bolts along a roadway much more accurately.

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# ANNEXURE 1

**SAMPLE NUMERICAL MODEL PROGRAM FOR 5 M THICK SEAM AT 150 M DEPTH:**

```
Title
S.K.Singh(final year project)
* Seam thickness= 5 m (Panel 16), Pillar size=25m, Depth=150m
* Gallery size=4.8m X 3m, Width of split=5m; Rib thickness=2.5m
*PARAMETRIC STUDIES
* Seam thickness=3-11m @2m, Pillar size=25m, Depth=150-900m @30m
* Gallery size=4.8m X 3m, Width of split=5m; Rib thickness=2.5m
GR 78 28
M M
gen 0,0 0,100 60,100 60,0                     R .8 .8      I 1 8   J 1 12
gen 60,0 60,100 64.8,100 64.8,0               R 1 .8       I 8 12  J 1 12
gen 64.8,0 64.8,100 72.25,100 72.25,0         R 1 .8       I 12 17 J 1 12
gen 72.25,0 72.25,100 77.25,100 77.25,0       R 1 .8       I 17 19 J 1 12
gen 77.25,0 77.25,100 85,100 85,0             R 1 .8       I 19 24 J 1 12
gen 85,0 85,100 89.8,100 89.8,0               R 1 .8       I 24 28 J 1 12
gen 89.8,0 89.8,100 92.3,100 92.3,0           R 1 .8       I 28 33 J 1 12
gen 92.3,0 92.3,100 97.25,100 97.25,0         R 1 .8       I 33 38 J 1 12
gen 97.25,0 97.25,100 102.25,100 102.25,0     R 1 .8       I 38 43 J 1 12
gen 102.25,0 102.25,100 110,100 110,0         R 1 .8       I 43 45 J 1 12
gen 110,0 110,100 114.8,100 114.8,0           R 1 .8       I 45 49 J 1 12
gen 114.8,0 114.8,100 117.3,100 117.3,0       R 1 .8       I 49 54 J 1 12
gen 117.3,0 117.3,100 122.25,100 122.25,0     R 1 .8       I 54 59 J 1 12
gen 122.25,0 122.25,100 127.25,100 127.25,0   R 1 .8       I 59 61 J 1 12
gen 127.25,0 127.25,100 135,100 135,0         R 1 .8       I 61 66 J 1 12
gen 135,0 135,100 139.8,100 139.8,0           R 1 .8       I 66 70 J 1 12
gen 139.8,0 139.8,100 200,100 200,0           R 1.2 .8     I 70 79 J 1 12
*Coal seam -9m
gen 0,100 0,105 60,105 60,100                 R .8 1 I 1 8          J 12 17
gen 60,100 60,105 64.8,105 64.8,100           R 1 1  I 8 12         J 12 17
gen 64.8,100 64.8,105 72.25,105 72.25,100     R 1 1  I 12 17        J 12 17
```

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gen 72.25,100 72.25,105 77.25,105 77.25,100          R 1 1  I 17 19          J 12 17
gen 77.25,100 77.25,105 85,105 85,100                R 1 1  I 19 24          J 12 17
gen 85,100 85,105 89.8,105 89.8,100                  R 1 1  I 24 28          J 12 17
gen 89.8,100 89.8,105 92.3,105 92.3,100              R 1 1  I 28 33          J 12 17
gen 92.3,100 92.3,105 97.25,105 97.25,100            R 1 1  I 33 38          J 12 17
gen 97.25,100 97.25,105 102.25,105 102.25,100        R 1 1  I 38 43          J 12 17
gen 102.25,100 102.25,105 110,105 110,100            R 1 1  I 43 45          J 12 17
gen 110,100 110,105 114.8,105 114.8,100              R 1 1  I 45 49          J 12 17
gen 114.8,100 114.8,105 117.3,105 117.3,100          R 1 1  I 49 54          J 12 17
gen 117.3,100 117.3,105 122.25,105 122.25,100        R 1 1  I 54 59          J 12 17
gen 122.25,100 122.25,105 127.25,105 127.25,100      R 1 1  I 59 61          J 12 17
gen 127.25,100 127.25,105 135,105 135,100            R 1 1  I 61 66          J 12 17
gen 135,100 135,105 139.8,105 139.8,100              R 1 1  I 66 70          J 12 17
gen 139.8,100 139.8,105 200,105 200,100              R 1.2 1 I 70 79         J 12 17
*Sandstone overburden
gen 0,105 0,255 60,255 60,105                        R .8 1.2 I 1 8          J 17 30
gen 60,105 60,255 64.8,255 64.8,105                  R 1 1.2  I 8 12         J 17 30
gen 64.8,105 64.8,255 72.25,255 72.25,105            R 1 1.2  I 12 17        J 17 30
gen 72.25,105 72.25,255 77.25,255 77.25,105          R 1 1.2  I 17 19        J 17 30
gen 77.25,105 77.25,255 85,255 85,105                R 1 1.2  I 19 24        J 17 30
gen 85,105 85,255 89.8,255 89.8,105                  R 1 1.2  I 24 28        J 17 30
gen 89.8,105 89.8,255 92.3,255 92.3,105              R 1 1.2  I 28 33        J 17 30
gen 92.3,105 92.3,255 97.25,255 97.25,105            R 1 1.2  I 33 38        J 17 30
gen 97.25,105 97.25,255 102.25,255 102.25,105        R 1 1.2  I 38 43        J 17 30
gen 102.25,105 102.25,255 110,255 110,105            R 1 1.2  I 43 45        J 17 30
gen 110,105 110,255 114.8,255 114.8,105              R 1 1.2  I 45 49        J 17 30
gen 114.8,105 114.8,255 117.3,255 117.3,105          R 1 1.2  I 49 54        J 17 30
gen 117.3,105 117.3,255 122.25,255 122.25,105        R 1 1.2  I 54 59        J 17 30
gen 122.25,105 122.25,255 127.25,255 127.25,105      R 1 1.2  I 59 61        J 17 30
gen 127.25,105 127.25,255 135,255 135,105            R 1 1.2  I 61 66        J 17 30
gen 135,105 135,255 139.8,255 139.8,105              R 1 1.2  I 66 70        J 17 30
gen 139.8,105 139.8,255 200,255 200,105              R 1.2 1.2I 70 79        J 17 30
PROP S=4.E9   B=6.67E9  D=2300 T=9.E6   C= 12.E6       FRIC=45 I 1 78 J 1 11
PROP S=4.E9   B=6.67E9  D=2300 T=9.E6   C=12.E6        FRIC=45 I 1 78 J 20 29
```

```
PROP S=2.2E9  B=3.67E9  D=1427 T=1.86E6 C=1.85E6   FRIC=30 I 1 78 J 12 16
PROP S=1.14E9 B=1.7E9   D=1850 T=.56E6  C=1.1E6     FRIC=35 I 1 78 J 17
PROP S=3.06E9 B=3.9E9   D=1850 T=2.8E6  C=2.1E6     FRIC=35 I 1 78 J 19
PROP S=4.E9   B=6.67E9  D=2300 T=9.E6   C=12.E6     FRIC=45 I 1 78 J 18
SET GRA 9.81
set large
set FLOW=OFF
FIX X I 1
FIX X J 1
FIX X I 79
FIX Y J 1
INI SYY -3.75E6 VAR 0 3.75E6
INI SXX -4.5E6 VAR 0 0.850E6
HIS NSTEP 10
HIS XDIS I 30 J 14
HIS YDIS I 30 J 14
HIS UNBAL I 1 J 1
MOD NULL I 8 11 J 12 13
MOD NULL i 24 27 j 12 13
MOD NULL i 45 48 j 12 13
MOD NULL i 66 69 j 12 13
*SOLVE
S=15000
***********
*With development only* Save as st5dh200.sav
***********
Save D:\Final\st5dh150dev.sav
******Split galleries 5m x 3m
***********OPENING OF SPLIT 1**********
MOD NULL I 17 18 J 12 13
***********OPENING OF SPLIT 2**********
MOD NULL i 38 42 j 12 13
************OPENING OF SPLIT 3**********
MOD NULL i 59 60 j 12 13
```

```
*
*SOLVE
s=15000
Save D:\Final\st5dh150split.sav
MOD NULL I 54 69 J 12 16
*SOLVE
s=19000
SAVE D:\Final\st5dh150EXP1.SAV
******************For extraction of two pillars
***************EXTRACTION OF PILLAR 2
MOD NULL I 33 48 J 12 16
**********
****After extraction of two pillars WITHOUT CABLES IN GOAF
********save as ncexp2C.sav
*SOLVE
s=15000
SAVE D:\Final\st5dh150EXP2.SAV
**********
***** FOR EXTRACTION OF 2.5 PILLARS with cable bolts in goaf
MOD NULL I 17 27 J 12 16
*SOLVE
s=15000
***** FOR 2.5 PILLARS EXTRACTION - SAVE AS NCEXP25C.SAV
SAVE D:\Final\st5dh150EXP25C.SAV
***********
*****After judicious rob and burst of rib 1
MOD NULL I 49 53 J 12 16
*SOLVE
s=16000
***** FOR 2.5 PILLARS EXTRACTION - SAVE AS NCEXP25R.SAV
***********
SAVE D:\Final\st5dh150EXP25R.SAV
RET
```